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- - (FOUO 17/79)

**1 OF 1**

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30 March 1979

TRANSLATIONS ON USSR SCIENCE AND TECHNOLOGY  
PHYSICAL SCIENCES AND TECHNOLOGY  
(FOUO 17/79)

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30 March 1979

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PHYSICAL SCIENCES AND TECHNOLOGY

(FOUO 17/79)

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CYBERNETICS

NATIONAL CONFERENCE IN KAZAN' ON OPTIMAL CONTROL IN MECHANICAL SYSTEMS

Moscow TEKHNIЧЕСКАЯ КИБЕРНЕТИКА in Russian No 6, Nov/Dec 1978 pp 209-210

[Article by F. L. Chernous'ko: "Chronicle -- The Second All-Union Conference on Optimal Control in Mechanical Systems"]

[Text] The Second All-Union Conference on Optimal Control in Mechanical Systems was held on 25-27 January 1978 in Kazan'. The conference was organized by the Institute of Problems of Mechanics of the Academy of Sciences USSR and the Kazan' Order of the Labor Red Banner Aviation Institute imeni A. N. Tupolev. Roughly 300 specialists from scientific research institutes, organizations, and higher educational institutions in Moscow, Leningrad, Kiev, Kazan', Sverdlovsk, Novosibirsk, Minsk, and other cities of the USSR took part in the work of the conference. At the conference 188 reports were presented, four in plenary session and 184 in sections. Compared with the First All-Union Conference on Optimal Control in Mechanical Systems, held 2-4 December 1974 at the Institute of Problems of Mechanics in Moscow, the number of reports increased substantially (almost triple) and the geographic representation was better.

Let us briefly review the content of the plenary reports.

T. K. Sirazetdinov and A. I. Gromov gave a report entitled "The Chief Task in Control of Mechanical Systems." It presents a general formulation of the task of synthesizing control systems from the point of view of meeting given technical specifications put in the form of constraints of the inequality type. The existence conditions for a solution to the problem are given. The report reviews research in this area and points out solution algorithms. The authors present a series of concrete engineering problems encompassed by this formulation and show the connection between it and problems of automating the design of mechanical systems.

N. N. Krasovskiy and Yu. S. Osipov presented a report entitled "Static Control of Evolutionary Systems." It was devoted to the problems of control of systems with distributed parameters in conditions of uncertainty. The authors considered general controlled evolutionary systems, in particular covering systems described by equations in partial derivatives, with incomplete information about phase state and disturbing forces.

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The authors give a rigid statement of the game problems of control for such systems and show the solubility conditions for the problems under consideration.

K. A. Lur'ye and V. A. Troitskiy presented a report entitled "Optimization of the Structure and Form of Elastic Design Elements." They cited results with optimization of various one- and two-dimensional elastic elements: cores, plates, and shells. The controls are the geometric or mechanical characteristics of an elastic body and the functionals are displacements, the weight of the elements, their own frequencies, or critical forces in loss of stability. The report describes ways to construct the necessary conditions of optimality, particularly by variation techniques. A number of special features of these problems are noted: disconnected and special solutions, tensor control functions, and the like. A number of solutions to problems of optimizing cores and plates are given.

F. L. Chernous'ko and A. A. Melikyan presented a report entitled "Problems of Information Control in the Games of Dynamic Systems." The report was devoted to differential games with incomplete information in which one or both players are unable to observe the opponent for the entire interval of movement; rather they can observe only part of the motion, at certain moments or intervals of time. The set of observation moments is either given or controlled by the players in the process of the game. A series of convergence and pursuit games with incomplete information was studied. The minimum information needed by the players to complete the game successfully is indicated.

The conference had four sections which held 28 meetings. The section on "Control of Complex Mechanical Systems" considered primarily problems of control of various technical systems with many degrees of freedom. Control algorithms were set forth and system dynamics investigated. The section on "Optimal Control of Movement" covered problems of the theory of optimal control of deterministic and stochastic systems, techniques of constructing optimal control, problems of differential games, and various applications of optimal control to dynamic systems. The section on "Optimal Control in the Mechanics of a Continuous Medium" was devoted to the theory of control of systems with distributed parameters, optimization of elastic and plastic bodies, and problems of optimization in hydrodynamics. The reports given in the section on "Optimization and Automation of the Designing of Mechanical Systems" dealt with problems of optimizing designs and their elements and questions of constructing algorithms for automation and optimization of design work.

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ELECTRONICS AND ELECTRICAL ENGINEERING

UDC 681.3.181.4

A SYSTEM FOR TESTING MICROPROCESSOR LARGE SCALE INTEGRATED CIRCUITS AND MICROPROCESSORS

Novosibirsk AVTOMETRIYA in Russian No 6, Dec 78-Jan 79 pp 33-42

[Article by B.I. Borde, Ye.A. Vysov, A.A. Zhuravlev and V.G. Cherepanov, Krasnoyarsk, manuscript received following revision 18 April, 1978]

[Text] The development of the production of large-scale integrated circuits (BIS) [LSI] is resulting in new requirements on test equipment, since LSI circuits are no longer simply structural components, but rather a complex functional circuit housed in a package with a limited number of leads and having a considerable number of internal states. In this regard, the process of testing large scale integrated circuits, among which processor components, microprocessors, memories (main memories and read-only memories) are included, is not effective when manual methods are used. Various methods and test stands are being developed for automated testing: specialized ones for testing one microcircuit type and all-purpose ones for testing LSI systems [1 - 6]. The latter have an advantage, since it is not necessary to design new equipment for each specific integrated circuit.

An all purpose system for testing LSI circuits is treated in this paper, where these circuits are compatible with TTL circuits in terms of the signals, and the system is based on a series produced microcomputer which permits the functional parametric and dynamic testing of large scale integrated circuits.

The system includes (Figure 1): a microcomputer with a set of peripherals, a well developed control unit for the peripherals and a group of peripherals (VU), one of which is the LSI testing peripheral unit. The computer is coupled to the UVU [peripherals control unit] through an input-output interface, to which a group of UVU's can be connected, as well as a PL-80 perforator control block incorporated in the computer complex, a peripheral memory, etc.

One of three microcomputers can be employed in the system, where these computers are compatible in terms of the instruction system and the input-output interface ("Elektronika S-50" [7], and others) and which have the following main characteristics:

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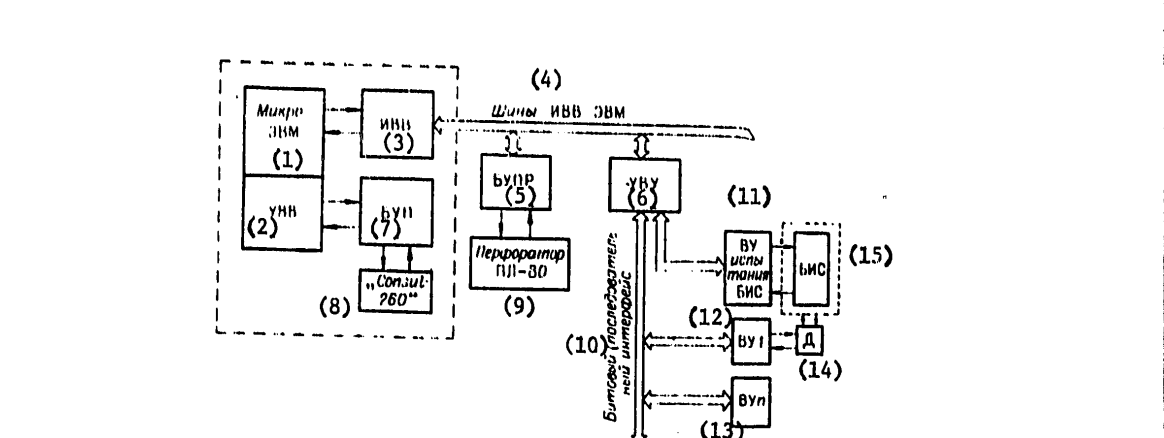


Figure 1. Block diagram of the LSI testing system designed around a microcomputer.

Key:

1. Microcomputer;
2. UVV [input-output unit];
3. IVV [input-output interface];
4. Computer input-output interface buses;
5. BUPR [perforator control block];
6. UVU [control unit for the peripherals];
7. BUP [printout control block];
8. "Consul-260";
9. PL-80 perforator;
10. Bit (series) interface;
11. LSI circuit testing peripheral unit;
12. VU 1 [peripheral 1];
13. VU n [peripheral n];
14. Transducers for climatic tests];
15. LSI circuit.

- The word format is 16 decimal digits (mantissa sign, 12 decimal mantissa digits, an exponent sign and two digits for the exponential order of magnitude);
- The time for executing short operations is 0.5 msec, and 2 msec for multiplication type operations;
- The volume of the S-50 computer memory is one Kbyte (without expansion);
- The computer input-output interface includes eight forward buses and eight return buses, four identification buses, five control buses and two priority service buses;
- The exchange rate with the peripherals is 10 Kbytes/sec;
- The exchange of data is accomplished in a binary-decimal code.

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The structure of the peripherals control unit. The coupling link between the computer and the group of peripherals is the peripherals control unit. Some eight peripherals can be connected to the UVU. Included among the functions performed by the UVU are: the reception of instruction messages from the computer, their conversion to the peripheral format and their transmission to the peripheral interface, the setting of the interval between readouts, the determination of the number of channels during the interval time between readouts, the reception of data from a peripheral, the conversion of the data to the computer format and its feedout to the input-output interface of the computer. An informational message for the UVU includes:  $L$  is the mark code field (highest order digit of the mantissa), which determines the number of the UVU and serves to address and identify it;  $M_2$  [ $I_1$ ,  $I_2$ ] are the code fields of the interval between readouts (two decimal digits),  $I_1$  determines the output of the frequency divider, which can be set within a range of  $10^{-3}$ -- $10^{-4}$  Hz, and  $I_2$  is a multiplier (which can vary from one to nine); the interval time between readouts in seconds is defined by the formula  $T = I_1/I_2$  and can vary within a range of from  $10^{-3}$  to  $9 \cdot 10^4$  seconds;  $K_1$  and  $K_2$  are the code fields of the number of channels (two decimal digits);  $P$  is the field of the code for the operating mode of the UVU; mantissa digits 7--12 are not used.

The peripherals control unit (Figure 2) includes the following: a code output register (RV); input diode gates [VV]; a readout interval setter (UZIO); a counter and register for the number of the channels (SCHK and RK); an instruction encoder (ShK); an identification decoder (DshI); a UVU selector (DSh UVU); a UVU--peripheral unit series interface block; a parallel interface block for the LSI peripheral unit and the control unit (UU). An input byte trunk is organized within the UVU for the addresses and data, as well as an output byte trunk for the data.

The operation of the major assemblies of the UVU was treated in [8]. The information exchange between the UVU and the peripheral is realized through the peripherals interface. Included in the functioning of the UVU--peripheral unit interface are the operations of decoding the peripheral unit address, synchronization during data exchange, the matching of the signal levels and formats of the information representation, the organization of interrogations, etc. For the purpose of reducing the number of galvanically isolated buses, used in the system is a series bit UVU--peripheral unit interface, which is intended for analog to digital conversion and digital to analog conversion interchange with a peripheral, as well as a half-byte interface to organize the interchange with the LSI testing peripheral. Its functions include the operations of information interchange between the UVU and the LSI peripheral. The LSI peripheral interface includes four forward transmit information buses, four return transmit information buses and three control buses.

The analog to digital and digital to analog converter peripherals were discussed in [9]. The LSI testing peripheral is intended for testing processor elements, memories (core storage and ROM's), as well as other microcircuits

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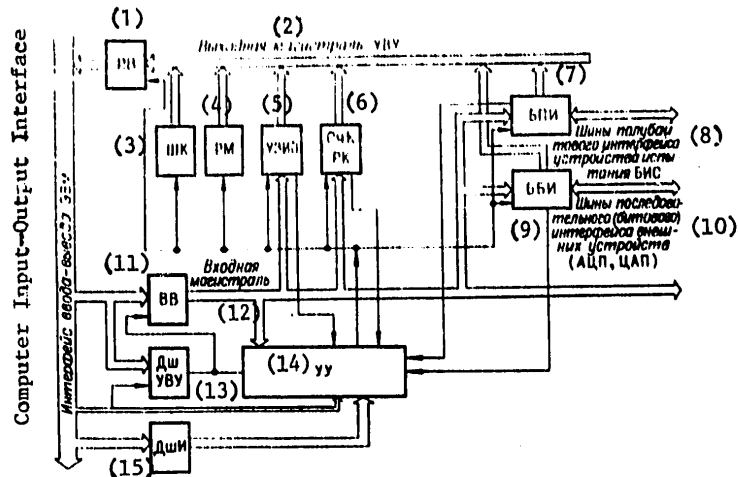


Figure 2. Block diagram of the control unit for the peripherals.

- Key:
- 1. RV [code output register];
  - 2. Main output trunk of the control unit for the peripherals;
  - 3. ShK [instruction encoder];
  - 4. RM [mantissa register];
  - 5. UZIO [readout interval setter];
  - 6. SchK [counter for the number of the channels];
  - 7. BPI [half-byte interface block for the LSI circuit peripheral unit];
  - 8. Half-byte interface buses for the LSI testing unit;
  - 9. BBI [bit interface block];
  - 10. Series (bit) interface buses of the peripherals (analog-digital converter, digital-analog converter);
  - 11. VV [input diode gates];
  - 12. Main input trunk;
  - 13. DSh UVU [peripherals control unit selector];
  - 14. UU [control unit];
  - 15. DShI [identification decoder].

The structure of the LSI testing peripheral includes the following (Figure 3): an instruction message register (P1); a reply message register (P2); a counter (Sch) [2] and a decoder (DSh) [9] for the interface sync pulses; a marker decoder (DShI) [3]; a clock frequency generator (UTCh) [4]; receive logic, information output logic and sockets for the connection of the LSI circuit.

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[Key to Figure 3 on preceding page]

Key: 1. SI [sync pulse];  
 2. SCh [interface sync pulse counter];  
 3. DSh 1 [marker decoder];  
 4. Clock frequency generator;  
 5. Sync pulse connecting socket;  
 6. VV [input diode gates];  
 7. Output connecting socket;  
 8. Output connecting socket;  
 9. DSh [interface sync pulse decoder];  
 Y[4] are the input and output half-byte buses of the interface;  
 P1 = instruction message register;  
 P2 = reply message register.

The instruction message register intended for receiving and storing an instruction message (two words 0, based on which the clock frequencies are generated and information is fed to the LSI. The word for setting the clock frequencies (word F) is intended for generating a sequence of synchronizing pulses in accordance with a specified code, where these pulses are necessary for the functioning of a specific LSI circuit. The information word of the LSI (the word M [I]) contains an operand on which operations are performed, an operational code and control signals in the case of microprocessor LSI's, or an operand and address when testing memories.

The structure of a message for specifying the clock frequencies is given in Table 1, and includes: the marker necessary for addressing the LSI peripheral, the F1 field determines the choice of the output of the decade frequency divider (from 10 MHz down to 1 Hz) by means of multiplexer M1 (Figure 4), the F2 field, which using multiplexer M2 determines the second frequency division stage (F2 = 1, 2, 4, 8). The remaining eight half-bytes of the word (field F3) specify the choice of the sequence of synchronizing pulses with programmable time delays, SI1, SI2, SI3, and SI4.

The structure of an information word for the LSI is shown in Table 1. The information word for a LSI includes: a marker, the M1 [I1 numerical data field, the M3 [I3] operation code field (address field when testing memories), and the M2 [I2] control signal field. The marker code is written into P1 upon the "receive" UVU signal and the code DSh = 1 [interface sync pulse decoder code = 1]. The authorization for the continued reception of the word F or the word I is based on the agreement of the "receive" signal with the control signal of the DSh and the signal of the marker decoder DSh1.

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Table 1  
Instruction Message to a Peripheral

(1)	Разряды мантиссы информационного сообщения ЦИМ	1	2	3	4	5	7	6	8	9	10	11	12
(2)	Возможные значения разряда мантиссы	0:9	0:9	0:9	0:9	0:9	0:9	0:9	0:9	0:9	0:9	0:9	0:9
(3)	Идентификатор поля слова F	M	F1	F2	F31	F32	F33	F34	F31	F32	F33	F34	
(4)	Возможные значения поля слова F	7	0:7	0:4	0:7	0:7	0:7	0:7	0:7	0:7	0:7	0:7	0:7
(5)	Назначение поля в ВУ	(6)	(7)	(8)	(9) Выбор								(10)
		Метка 7	Частота	Делитель	CH 11	CH 12	CH 13	CH 14	CH 21	CH 22	CH 23	CH 24	
(11)	Значение поля слова И для БИС K584IK1	8	0:1	0:7	0:4	0:4	0:1	0:7	0:3	0:7	0:2	0:4	1
(12)	Назначение поля в ВУ при передаче слова И для БИС K584IK1	Метка 9	Шина ВХ 3	Шина ВХ 2:0	Слово адрес 1	Слово адрес 2	Слово адрес 3	Слово кода операции (13)					Управление процессором БИС
		14	15	16	17	18	19	Вход переключателя	Программный счетчик ОП1	ОП2 ÷ ОП4	ОП5 ÷ ОП6	ОП7 ÷ ОП9	
								Управление процессором БИС	Управление процессором БИС	Управление процессором БИС	Управление процессором БИС	Управление процессором БИС	10

- Key: 1. Mantissa digits of the computer information message;  
 2. Possible value of a mantissa digit;  
 3. Word field Word field identifier, F;  
 4. Possible value of the field of word F;  
 5. Designation of the field in the peripheral;  
 6. Marker 7;  
 7. Frequency;  
 8. Divider;  
 9. Choice;  
 10. Not used;  
 11. Value of the word field И [I] for a K584IK1 LSI;  
 12. Designation of the field in the peripheral unit when transmitting the word I for a K584IK1 LSI;  
 13. Operation code word;

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[Key to Table 1 continued]:

14. Marker 8;
15. Input buses 3;
16. Input buses 2 -- 0;
17. Shift to the right 1, shift to the left 1;
18. Shift to the right 2, shift to the left 2;
19. Carry input of the program counter OP1;
20. OP2 -- OP4;
21. OP5 -- OP6;
22. OP7 -- OP9;
23. Control of the positions of the SLI;
24. Increment control. Priority.

The reply message register (P2) is intended for the reception, storage and output of the LSI reply message to the interface buses. The structure of the reply message is given in Table 2. The signals for writing the information into the register are set by the operator at the connecting socket for the sync pulses. Data is fed out then to the trunk upon the "transmit" signal using half-bytes.

The clock frequency generator (see Figure 4) consists of an  $f = 10$  MHz pulse generator, a two stage frequency divider (SCHF, SCH10, M1 and M2), decimal counters with decoders, where a sequence of pulses shifted by one-half period is fed to one of the decoders, eight multiplexers for selecting two sequences of sync pulses in accordance with the F message, where these pulses are shifted with respect to each other (SI1 and SI2) and two sequences of pulses (SI3 and SI4) which are determined by the combinations of SI1 and SI2 (see Figure 4). The widths of the SI1 and SI2 synchronizing pulses are determined by the F1 and F2 fields of the register P1:  $\tau_{SI1} = \tau_{SI2} = F2/F1$ , where F1 specifies the choice of the frequency within a range of  $10^6$  --  $10^{-1}$  Hz, and F2 specifies a multiplying factor (1, 2, 4 or 8). The widths of the SI3 and SI4 synchronizing pulses are determined as combinations of SI1 and SI2 in accordance with Figure 4 based on the following formulas:

$$\begin{aligned} \tau_{CH1} &= \tau_{CH1} + \frac{\tau_{CH2}}{2}; & \tau_{CH1} &= \tau_{CH1} - \frac{\tau_{CH2}}{2}; \\ \tau_{CH2} &= \tau_{CH2} + \frac{\tau_{CH3}}{2}; & \tau_{CH2} &= \tau_{CH2} - \frac{\tau_{CH3}}{2}; \\ \tau_{CH3} &= \tau_{CH3} + \frac{\tau_{CH4}}{2}; & \tau_{CH3} &= \tau_{CH3} - \frac{\tau_{CH4}}{2}; \\ \tau_{CH4} &= \tau_{CH4} + \frac{\tau_{CH5}}{2}; \end{aligned}$$

[CH = SI = synchronizing pulse]

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The requisite synchronizing pulses for controlling a specific LSI are switched at the sync signal socket.

**Table 2**  
**The Reply Message of a Peripheral**

(1)	Реплика Mantissa кода информации компьютера 2033	1	2	3	4	5	6	7	8	9	10	11	12
(2)	Возможное значение разряда Mantissa	0 ÷ 9	0 ÷ 9	0 ÷ 9	0 ÷ 9	0 ÷ 9	0 ÷ 9	0 ÷ 9	0 ÷ 9	0 ÷ 9	0 ÷ 9	0 ÷ 9	0 ÷ 9
(3)	Идентификатор слова И	М	ИИ1	ИИ2	ИИ3	ИИ4	ИИ5	ИИ2	ИИ3	ИИ4	ИИ1	ИИ2	—
(4)	Цель поля при тестировании К584ИК1	8	0 ÷ 1	0 ÷ 7	1 ÷ 4	1 ÷ 4	0 ÷ 1	0 ÷ 7	0 ÷ 1	—	0 ÷ 2	0 ÷ 7	—
(5)	Назначение поля при тестировании К584ИК1	Метка 8	Шина Вых 3	Шина Вых 2 ÷ 0	Сдвиг вправо 1 Сдвиг влево 1	Сдвиг вправо 2 Сдвиг влево 2	Шина А3	Шина А2 ÷ А0	Старший бит регистра расширения	Не используется	Сигналы ускоренного переноса	Управление инкрементом	Не используется
		6	7	8	9	10	11	12	13	14	15	16	17

- Key: 1. Mantissa digits of the computer information message;  
 2. Possible value of a mantissa digit;  
 3. I field identifier;  
 4. Value of the I word field for a K584IK1 LSI;  
 5. Purpose of the field when testing a K584IK1 LSI;  
 6. Marker 8;  
 7. Output bus 3;  
 8. Output buses 2 -- 0;  
 9. Shift to the right 1, shift to the left 1;  
 10. Shift to the right 2, shift to the left 2;  
 11. Bus A3;  
 12. Buses A2 --A0;  
 13. Highest order bit of the expansion register;  
 14. Not used;  
 15. Carry accelerate signals;  
 16. Increment control;  
 17. Not used.

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The automated LSI testing system was used for I<sup>2</sup>L testing [10] of a K584IK1 microprocessor. The requisite conditions for testing the microprocessor are the generation of a controlling code for the operations, the code for the number transmitted to the LSI, and the control signals for the positions, priority, etc., the reception of the number code and the address code of the LSI, as well as the carry signals, etc.

The structure of the instruction and reply messages for a K584IK1 microprocessor are shown in Table 1 and 2. The base eight numeration system is used for the information interchange. In view of the fact that the K584IK1 microprocessor (MP) has a large number of instructions (512) the testing program was broken down into several subroutines, executed sequentially using the same algorithm. An analysis of the results of the subroutine run shows the absence or presence of a dropout in the given group of instructions, and it is necessary to run all subroutines to check all 512 instructions. The algorithm for the microprocessor test is run in the following sequence:

1. Primary loading of the peripherals control unit (the computer transmits the information message for setting the operational mode to the peripherals control unit).
2. The transmission to the LSI peripheral unit of the word F for specifying the sequence of clock pulses needed to check the microprocessor for its operating frequency.
3. The input of the first group of instructions for checking in the subroutine.
4. The generation of the current information word for the LSI, which determines the type of instruction being executed and the operand on which the operation is performed.
5. The transmission of the information word to the LSI peripheral unit.
6. The triggering of the microprocessor at its working frequency to execute one instruction.
7. The reception of the result of executing specified instruction.
8. The analysis of the completion of the specified group of instructions.
9. Checking the result of executing the group of instructions. If the result is not correct, an analysis is carried out for the chance of a failure, for which the given group of instructions is executed three times after which a failure readout is accomplished.



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[Key to Figure 4]:

- Key: 1. Frequency divider, SChF;  
2. G [pulse generator];  
3. T [flip-flop for triggering the clock frequency generator to generate a series of synchronizing pulses];  
4. M [multiplexers for selecting the code sequences to generate the sync pulses];  
5. SCh [counter];  
6. DSh [decoder];  
CH = Synchronizing pulses.

\* \* \*

10. In the absence of a failure, a check for completion is made, and if the last subroutine has been run, the computer indicates the good operating condition of the microprocessor, otherwise, it moves on to the next processing subroutine.

Core storage with a volume of 8 Kbytes is necessary for a complete check of microprocessor functioning, while to check individual groups of instructions, the requisite volume of the core storage falls in range of one to four Kbytes.

Besides testing LSI's, the system developed here permits checking and debugging subroutines which executes specific algorithms, by means of specifying a sequence of codes for microprocessor instructions which are needed to realize a specific operation (addition, multiplication, etc.). In this case, the result of an operation is obtained over several cycles, determined by the depth of the subroutine for a specific operation, while the result of its execution is indicated on the computer. A programming change in the clock frequencies and widths of the sync pulses permits checking the working range of frequencies of a LSI, and when other analog-digital and digital-analog converter peripherals are used, permits the performance of climatic tests and tests of the power supply parameter scatter. A drawback to the system developed here can be considered the necessity for working in a base-eight system, the limited volume of the computer memory and its slow speed. The system is designed around K-155 series integrated circuits of a midrange level of integration. A general view of the system is shown in Figure 5.

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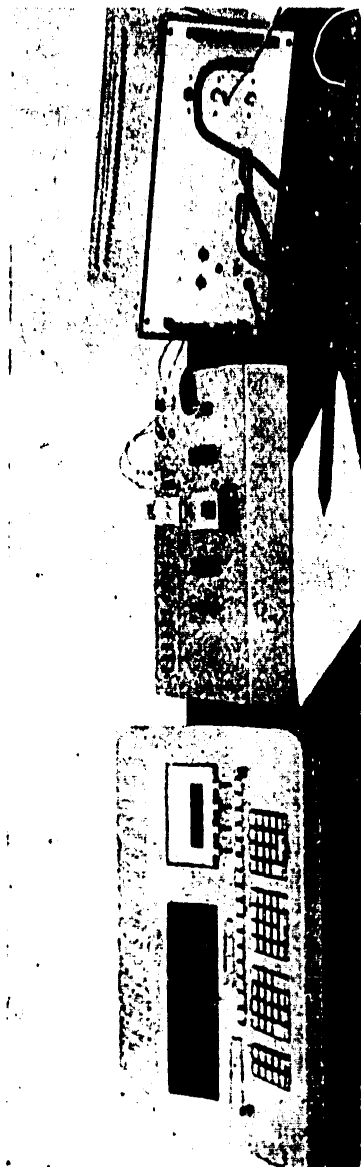


Figure 5. General view of the LSI test system (in the center is the peripheral unit for LSI testing, and at the right is the unit for controlling the peripherals).

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ELECTRONICS AND ELECTRICAL ENGINEERING

UDC 681.33

A SIGNAL MEASUREMENT METHOD FOR WIDE RANGE INFORMATION GATHERING AND PROCESSING SYSTEMS

Novosibirsk AVTOMETRIYA in Russian No 6, Dec 78-Jan 79 pp 91-95

[Article by V.R. Voznyuk, B.M. Glinskiy and V.M. Ivanov, manuscript received 6 February, 1978]

[Text] When designing digital systems which realize information retrieval and processing in real time in a wide amplitude range, there arises the problem of converting the analog signals to a code with a constant relative quantization error over the entire range.

For example, such a problem occurs when processing geophysical information using the method of the formation of a field in the near field, where it is necessary to record the formation process curve in wide ranges of time ( $10^{-4}$  --  $10^2$ ) and amplitude ( $10^6$ ) [1]. The processing unit should automatically record the signal (the e.m.f. from the receiving circuit) throughout the entire amplitude range with a specified error. The e.m.f. curve can be conventionally broken down into three ranges with respect to time: "early times" (the signal many times exceeds the noise), "mean times" (commensurate with the noise), and "later times" (many times less than the noise). In the second and third ranges, it is necessary to use special methods of signal detection: storage, and the suppression of periodic and pulse interference.

The problem posed here can in principle be solved using the device described in paper [2]. The device contains binary amplifiers, an analog-digital converter, comparison gates, switches and a computer, which on the basis of two readouts makes a linear extrapolation of the signal, and for the point in time of measurement, generates such a gain that the maximum number of digits is used in the analog-digital converter. Such a device will operate efficiently when processing comparatively "smooth" signals and can lead to substantial errors when measuring a signal under conditions of strong interference (the point in time of the measurement can coincide with an interference spike, and the digit network of the analog-digital converter will overflow). A drawback to this device is also the presence of a special computer block for signal extrapolation, the operational speed of which limits the use of the device in measuring high frequency signals.

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The drawbacks indicated here can be eliminated by means of a simpler method of selecting the gain of the binary amplifier. The essence of the method consists in the fact that prior to measurement, during a specified time interval, the mixture of signal and interference is observed, in which case the greatest value of the mixture of signal and interference is registered, i.e., the minimum gain at which the possibility of measuring signals which exceed the dynamic range of the analog-digital computer is precluded, and the signal is recorded at this gain at a specified point in time. In this case, the possibility of quantizing the signal while not completely using the digit capacity of the analog-digital converter is not precluded, something which can lead to an increase in the signal measurement error. However, it was shown in paper [3] that for steady-state interference with a normal distribution of the instantaneous values of the amplitudes, the signal measurement error weakly depends on the analog-digital converter quantum, for the case of a sufficient number of averagings. It follows from an expression  $\delta$ , derived in this paper, for the measurement of signal in the presence of interference, taking the quantization error into account, that when  $\sigma/q \geq 1$  ( $\sigma$  is the mean square deviation of the interference,  $q$  is the analog-digital converter quantum), the measurement error practically does not depend on the size of the analog-digital converter quantum,  $\delta \approx \sigma/U_0\sqrt{N}$ , and is determined by the number of repetitions  $N$  ( $U_0$  is the measurement signal).

Shown in Figure 1 is the circuit of a device which amplifies and converts a signal, and which operates using the proposed method. The device functions in the following manner: at the initial point in time, the flip-flops are reset, and then at a selected point in time, an instruction arrives which sets the time interval prior to measurement and registers the gain of the binary amplifier (FKU). When measuring a signal without interference, the width of this instruction can be extremely small, and it should immediately precede the signal measurement. In the presence of interference, this interval should be determined by the nature of the interference, and in this case, the greatest value of the mixture of signal and noise is registered in the RS flip-flops, which are controlled by comparators (i.e., the minimum gain is noted). In fact, if the signal at the output of a particular amplifying gate exceeds the comparison level of the comparator, then there appears at the output of the comparator the corresponding logic "1". Thereafter the flip-flop accuates, which through the AND gate inhibits the connection of the output of this element to the input of the analog-digital converter and authorizes the connection of the former [the flip-flop]. It is expedient to choose the comparison level somewhat lower than the maximum voltage being converted by the analog-digital converter. Upon the instruction to determine order of magnitude (OP), a binary exponent  $a_2$  is generated at the output of encoder CD, where this exponent describes the selected gain  $K = 2^{a_2}$ . Upon the same command, the corresponding switch (K) is turned on, through which the signal flows from the output of the selected amplifying element to the analog-digital converter. The "conversion" instruction triggers the analog-digital converter, which initially stores the signal being measured at the specified point in time by means of a comparator clamp for the voltage

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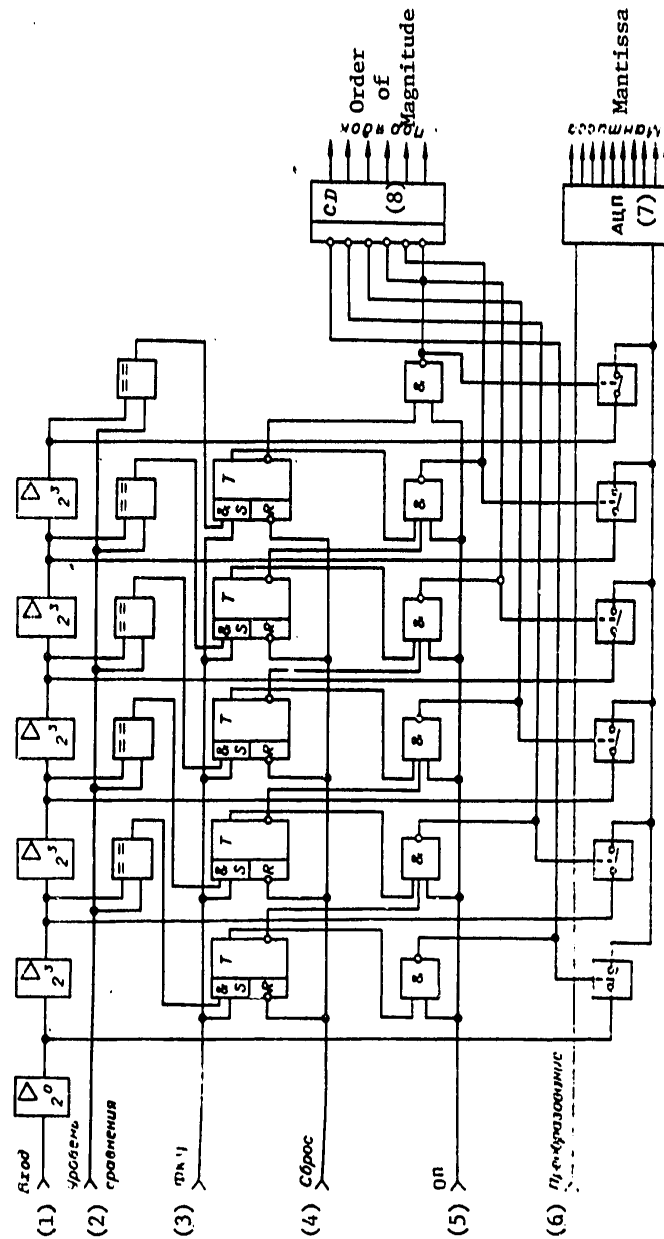


Figure 1.

- Key: 1. Input;  
2. Comparison level;  
3. Binary amplifier gain instruction;  
4. Reset;
5. Instructions for the order of magnitude determination;  
6. Conversion;  
7. Analog-digital converter;  
8. CD [encoder].

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level [4], and then converts it to a  $\pm A_2$  code. Thus, the signal being measured is represented in the form of a binary number with a floating decimal point,  $\pm A_2 \cdot 2^{a_2}$ . This numerical form permits the representation of signals in a wide range of amplitudes and is most advantageous from the viewpoint of equipment outlays when performing storage operations in a processor.

The time interval set aside for observing the interference is determined by the spectral composition of the interference and the variation in the amplitude of the signal being measured. If during the observation interval, the interference characteristics do not change substantially, then the interference at the input to the amplifier can be assessed as a steady-state random process. Then one can determine the average number of overshoots  $P$  (ST) at a level  $C$  over a time  $T$  for normal noise with a uniform spectral density in a range of frequencies from 0 up to  $\Delta f$  [5]:

$$P(C, T) = \frac{T \Delta f e^{-\sqrt{3} C / \sigma}}{\sqrt{3}}$$

where  $C$  is the comparison level;  $\sigma$  is the mean square deviation of the interference. The time interval over which  $P$  overshoots can occur is determined from this:

$$T = \frac{P \sqrt{3} e^{\sqrt{3} C / \sigma}}{\Delta f}$$

Let us assume that it is necessary to find the time interval in which even only one overshoot occurs at the input of a particular amplifier gate, where  $C/\sigma = 1$ . Then, for the case of a frequency bandwidth of  $\Delta f = 100$  KHz, one can determine the requisite time interval  $T \approx 24$   $\mu$ sec.

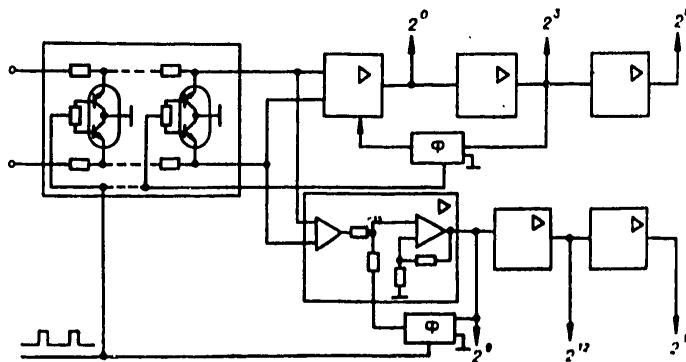


Figure 2.

The given binary amplifier circuit design having automatic selection of the gain was realized in the "Zond-1" equipment, intended for operating on the basis of the method of field formation in the near field [6]. The time for

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observing the interference was  $T = 25 \mu\text{sec}$ , and the comparison level was equal to 2 volts. An analog-digital converter with digit by digit equilibrating with 10 digits (including the sign) was used to represent the mantissa of the number ( $U_{\text{max}} = \pm 2.555$ , with a 5 mv quantum) [7]. The gain  $KK$  could assume the following values:  $2^0$ ,  $2^3$ ,  $2^6$ ,  $2^9$ ,  $2^{12}$ , and  $2^{15}$ . The amplifier and the analog-digital converter, in conjunction with the processor, provide for signal measurement in a range of from  $\pm 2.555$  down to  $\pm 10^{-6}$  volts. The resolving power of the amplifier and converter channel amounts to  $\pm 0.15 \mu\text{V}$  where the number of repetitions is  $N = 2^{14}$ .

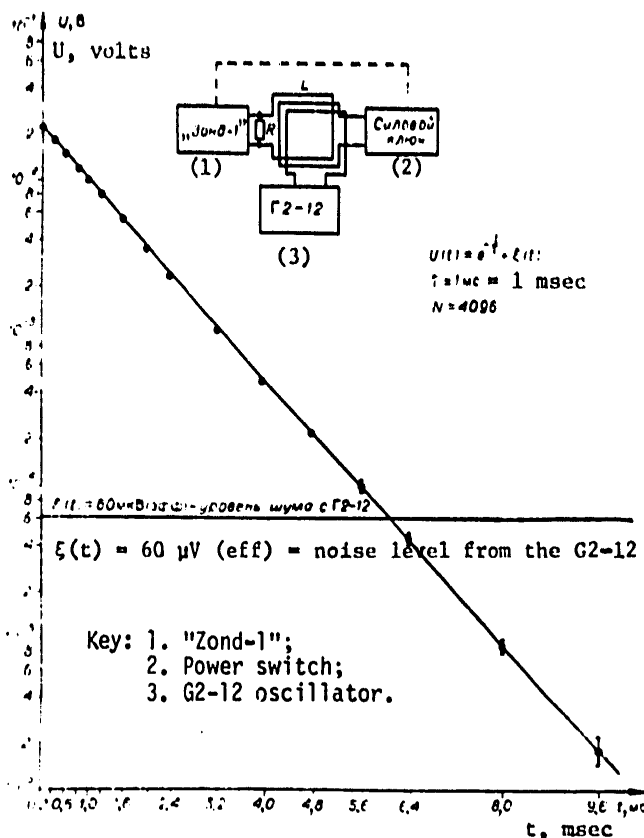


Figure 3.

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The amplifier consists of two groups of binary amplifiers: a multistage input switch, intended for protecting the amplifier against overvoltages in the initial stage of the transient process, and for sampling the signal at specified points in time (Figure 2). The input stages are designed in a differential configuration, something which allows for a substantial reduction in the influence of external interference and induced noise.

It is difficult to achieve considerable suppression of in-phase interference in a wide dynamic range, and for this reason, a circuit configuration was chosen for the amplifier which consists of two sections. One amplification section operates in a range of input signals of from  $4 \cdot 10^{-3}$  up to 2.5 volts and has a suppression factor for in-phase interference of 60 dB; the second is intended for input signals of less than  $4 \cdot 10^{-3}$  volts and has a suppression factor for in-phase interference of 95 dB. The amplifiers are designed in a configuration having automatic zero drift correction. For this purpose, the pulses which control the closing of the input switch, simultaneously enable the fine tuning of the zero level of the amplifier gate, connected in a level clamping (F) feedback circuit. When measuring the signal, the input switch is opened, however, the zero level of the element is preserved by virtue of the correction voltage which is stored in the clamp device. The shunt-type input switch consists of five series switches using 1KT011 integrated microcircuits and can suppress an input effect by  $32 \cdot 10^5$  times.

The input stages of both sections are designed around field effect transistors, which are selected in pairs, the operational point of which is fixed at the temperature independent point to reduce the influence of temperature on the drift of the input stages. The amplifier stages are designed around 1UT401B operational amplifiers and have a gain error of no more than 1% in a temperature range of from  $-10^\circ$  to  $+40^\circ$  C. The internal noise voltage, referenced to the amplifier input in a frequency range of 0 -- 100 KHz, amounts to an effective value of 10  $\mu$ v.

Shown in Figure 3 are the results of a calibration curve measurement of the "Zond-1" station. An exponential curve was fed to the input of the amplifier, driven by rectangular pulses from the power switch, with additively superimposed noise. The exponential time constant was  $\tau = L/R = 1$  msec, and the noise level was 60  $\mu$ v (eff). The exponential curve was recorded at 16 time points, distributed with a progressive step. Some 10 curves were reported in time range of from 0.2 to 9.6 msec where the number of repetitions was  $N = 2^{12} = 4,096$  (one realization). The calculated curve is indicated in the Figure [4] by the solid line, while the averaged results over the 10 realizations are indicated by the dots, while the small line segments indicate the maximum deviations of the measured voltages, obtained with even just one realization. The maximum error for these results does not exceed 26% ( $t = 9.6$  msec) for the case of a computed signal value at this time point of  $U_0 = 1.8$   $\mu$ v.

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GEOPHYSICS, ASTRONOMY AND SPACE

UDC 550.831.016

RESULTS OF EXTRAPOLATION OF GRAVITY ANOMALIES IN STRUCTURAL GRAVIMETRIC EXPLORATION

Moscow PRIKLADNAYA GEOFIZIKA in Russian No 89, 1977 pp 87-96

[Article by Yu. V. Antonov]

[Text] The use of extrapolation in ore gravimetric exploration [5] is not accidental. Here the sources of gravitational anomalies most frequently occupy relatively small volumes and therefore the anomalies are characterized by a more distinct localization than in structural gravimetry. On the basis of the distribution (in the vertical plane  $xOz$ ) of gravitational anomalies obtained by means of extrapolation, there can be effective separation of complex anomalies into local anomalies and it is possible to determine excess masses, densities and other parameters of anomalous bodies, whose determination by usual methods is not always stable and sufficiently precise.

In structural gravimetry the situation is more complex. The sources of the anomalies most frequently are different complexes of sedimentary rocks having different densities. Local anomalies are created either due to a change in the thickness of the strata of sedimentary rocks or by their spatial position (density within the strata is assumed to be homogeneous). In a mathematical sense in both cases the gravity anomalies are completely determined by the geometry of the discontinuities between strata of sedimentary rocks of different density. In this connection the final objective of the inverse problem in structural gravimetry is finding the form of the contact surfaces. In the case of a single contact surface this problem is solved with an accuracy which is more or less satisfactory for practical purposes [6, 7]. But the problem is greatly complicated if there are two or more contact surfaces.

Due to the peculiarities of structural gravimetry it is impossible to use the spatial distribution of gravity anomalies (especially in the presence of several discontinuities) in the same way as in ore gravimetric exploration. Accordingly, it is necessary to develop a method for the use of extrapolation in solving the formulated problem.

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One of the methods for solving the inverse problem for a contact surface in the presence of several discontinuities was described in [2]. The essence of the solution essentially involves discrimination of the transformed function  $G_z$  from the observed field; this function is related to the relief of the upper contact surface.

This method for constructing a contact surface was tested for determining the top of the Bukharskiye deposits in the Afghan-Tadzhik depression, which was filled with sedimentary deposits of Mesozoic-Cenozoic age, folded into complexly structured anticlinal folds of submeridional strike. The thickness of the sedimentary cover varies in a wide range, in the central part of the depression attaining 10 km or more. In the sedimentary stratum there are several discontinuities. The clearest density discontinuities are: 1) the boundary between the folded consolidated basement and the sedimentary cover; 2) the boundary associated with the top of the calcareous Jurassic, above which there are strata of salt-bearing-anhydrite deposits and continental deposits of the Lower Cretaceous; 3) the boundary of dolomitic-calcareous deposits of the Upper Cretaceous and the bottom of the Paleogene (including the Alayskiye and Bukharskiye layers) with the upper part of the clayey strata of the Paleogene and terrigenous formations of Neogene age; 4) the boundary of unconsolidated deposits and bedrock.

Quaternary deposits in disconformity cover the rocks of almost all age formations; therefore, at this density discontinuity the excess density varies in wide limits. The density of the Quaternary deposits was determined for the most part on the basis of gravimetric data [5] and was about 1.8-2.0 g/cm<sup>3</sup>. Individual determinations of the density of Quaternary deposits from borehole cores gave approximately the same results. The excess density at this discontinuity, depending on the age of the deposits covered by the Quaternary deposits, can vary in a wide range -- from 0.2 to 0.8 g/cm<sup>3</sup>. The mean weighted density of the Neogene and Upper Paleogene deposits is about 2.3 g/cm<sup>3</sup>; the Quaternary formations, with the exception of the arched parts of anticlinal structures, cover precisely these deposits, and therefore, on the average, the excess density is about 0.4 g/cm<sup>3</sup>.

The most studied boundary is that which is associated with the top of limestones in the Bukharskiy stage of the Paleogene. There have been numerous determinations of density from the outcrops of Bukharskiye limestones in anticlinal structures at the surface and from the cores of a great number of boreholes. The mean weighted density of the Lower Paleogene and the Upper Cretaceous is 2.55 g/cm<sup>3</sup>. Accordingly, the excess density can be assumed equal to 0.25 g/cm<sup>3</sup>.

The calcareous deposits of the Upper Cretaceous undergo transition into Lower Cretaceous terrigenous formations and the density gradually smoothly decreases (to 2.45 g/cm<sup>3</sup>); therefore, it is impossible to discriminate a significant graviactive discontinuity. On the other hand, at the boundary of the Lower Cretaceous deposits and the calcareous rocks of the Jurassic the density increases in a jump; its excess value here is not less than

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0.15 g/cm<sup>3</sup>. The excess density can also be considerably greater in the presence of a salt-anhydrite stratum associated with the bottom of the Lower Cretaceous. The Jurassic limestones are accessible by drilling only in individual places and therefore the completeness of information on the effective density at this discontinuity to a considerable degree is inferior to the volume of information from the upper part of the geological section to the Bukharskiye limestones inclusive.

The folded consolidated basement is at a depth of more than 6 km. Information on the density difference at the boundary with the sedimentary cover is available only along the peripheral parts of the Afghan-Tadzhik depression.

Jurassic and Bukharskiye calcareous deposits are promising deposits for petroleum and gas. Petroleum and gas deposits have already been explored and operated in these deposits. Since the Bukharskiye rocks almost everywhere can be reached by drilling, a determination of the depth of the top of the Bukharskiye limestones is of practical interest.

The described region is tectonically active. The Bukharskiye limestones are bent into complex anticlinal folds which in many cases have a length of several tens of kilometers. The tops of the structures usually have steep dips (up to 60° or more). Within the limits of the folds in many cases there are dislocations (primarily in the form of thrusts and faults), sometimes attaining more than 1 km in amplitude. The synclinal downwarps are filled with Quaternary and Neogene deposits. The thicknesses of the Neogene and Quaternary deposits are approximately comparable. The excess density of the entire complex of deposits in the synclines relative to the Bukharskiye limestones will be about 0.30-0.35 g/cm<sup>3</sup>.

After a brief geological description we will discuss the method for determining the form of the contact surface for the Bukharskiye limestones for the most studied sector of the Afghan-Tadzhik depression.

Figure 1 shows a schematic geological section through two anticlinal structures. The section shows only the boundary of the top of the Bukharskiye layers, constructed using drilling data and geophysical surveys. Both structures have been well studied by drilling and a gas-petroleum deposit, now in operation, is associated with one of them. In the synclinal zones the top of the Bukharskiye layers was determined on the basis of the correlation dependences of the transformed gravity anomalies with data from drilling, seismic prospecting and electric prospecting [5].

The gravitational field has an extremely complex structure and is governed by numerous factors. In particular, the field is characterized by sharp and intensive change in the regional background, caused by the deep peculiarities of the region, relating to the alpine zone. The anticlinal structures in the gravitational field are manifested in the form of relatively positive local anomalies. These anomalies over the structures reflect the

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Influence of all the density discontinuities. Accordingly, from the observed field it is necessary to discriminate that effect which is determined only by the boundary of the Bukharskiy stage.

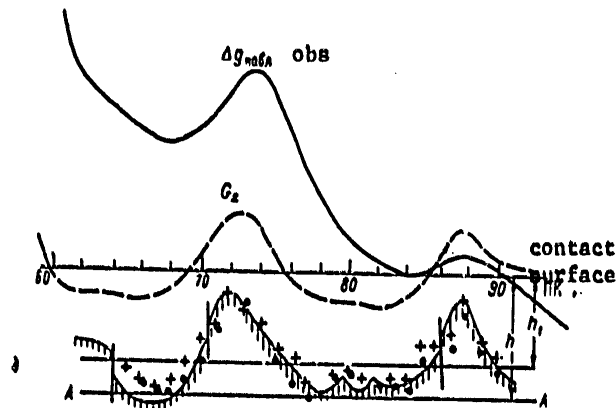


Fig. 1. Example of structure of contact surface.

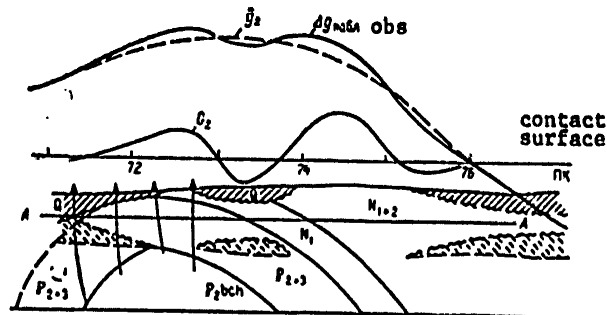


Fig. 2. Exclusion of local gravity anomalies caused by Quaternary deposits from observed gravity values.

We will begin with the exclusion of local gravity anomalies which are created by the boundary of the unconsolidated deposits with the bedrock. In the synclinal zones the Quaternary deposits lie virtually in conformity on the Neogene deposits (reference is to structural, not stratigraphic conformity) and almost horizontally. So that if the discontinuity between the Neogene and Quaternary deposits in the synclines creates a gravitational anomaly,

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it is of an extremely low intensity. However, in the region of local structures, where the bedrock outcrops at the surface and has steep dips, the Quaternary deposits exert an appreciable influence. However, if the bottom of the unconsolidated deposits is known, its influence is taken into account by solution of the direct problem. In the specific case it is possible to carry out averaging of the observed field and since the anomaly created by the bottom of the unconsolidated deposits is not commensurable with respect to correlation radius with the anomaly from the main structure, the averaging lessens the influence of the unconsolidated deposits. However, here the problem of the choice of the optimum averaging radius will remain open.

Unfortunately, it is not always possible to know the behavior of the bottom of these unconsolidated deposits and there is not necessarily a significant difference in the correlation radii from unconsolidated deposits and from the lower-lying graviactive boundaries.

Assume that the form of the surface between the unconsolidated deposits and the bedrock, as well as the excess density at this boundary are unknown. We know only the maximum depth at which it lies. Using the distribution of the vertical component  $g_z(\Delta g_{obs})$  on the observation profile we compute the horizontal component  $g_x$ . After this we take the profile A-A (Fig. 2) in the lower half-space situated at a depth of 400 m. This value is selected on the basis of the fact that the Quaternary deposits are situated above the profile but the Bukharskiye limestones are situated below it.

Then, using extrapolation [2], on the basis of the distribution of the  $g_x$  component at the surface, we find the  $g_x$  values on the A - A profile. Since the sign of the  $g_x$  component on it is not dependent on where the anomaly-forming masses are situated (above or below the profile), the unconsolidated deposits can move from top to bottom, that is, their mirror reflection relative to A - A is possible (Fig. 2 shows the reflected masses by a dashed line).

Then, on the basis of the  $g_x$  distribution on the A - A profile we compute the distribution of the component  $g_z$  [2]. It is easy to understand that the  $g_z$  values, due to the fact that the  $g_x$  sign is not dependent on the position of the masses, on the A - A profile will be equal to the sum of the attractions of the Bukharskiye limestones and the unconsolidated deposits, although a difference would be obtained on this profile in the case of direct gravity measurements. The determined  $g_z$  values can also be determined physically as the total attraction of the Bukharskiye limestones and some fictitious masses, being a mirror reflection of unconsolidated formations and situated below the A - A profile. Such a physical interpretation makes further conclusions simpler. After this the  $g_z$  values are scaled by means of analytical continuation upward to the observation surface. Such continuation does not change the spatial position of the top of the Bukharskiye limestone and the fictitious masses relative to the observation profile.

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As a result, on the observation profile we obtain a curve of the measured gravity values and some transformed function  $g_z$  in which the influence of the Quaternary deposits is replaced by the influence of the fictitious masses situated below the A - A profile. If we take the difference between these curves, then, obviously, the influence from the top of the Bukharskiye limestones and other underlying discontinuities will be excluded. The composite curve  $G_z$  [4] will contain only the difference effect from Quaternary deposits situated below the observation surface and fictitious masses situated at a depth of 800 m and being a mirror reflection of the Quaternary deposits.

Then we will solve the inverse problem for the  $G_z$  function, as was proposed in [4]. We immediately note that due to the conditions of the problem we do not know the excess density, which, in addition, can vary within the limits of the structure, depending on what deposits are in contact with the Quaternary formations. In solution of the inverse problem we find the gravitational effect, which is related only to the upper boundary [4], that is, to the unconsolidated deposits. This effect is related to the mean depth of the upper boundary. Then, in order to find the effect of attraction on the observation profile from the unconsolidated deposits, it is sufficient to carry out analytical continuation from the mean depth to the surface. Thus, there is no need to determine the position of the bottom of the unconsolidated deposits and then solve the direct problem for the purpose of evaluating the effect of attraction. The  $G_z$  value is almost equal to the attraction of the unconsolidated deposits, since the fictitious masses, situated at a depth of 800 m, exert no appreciable influence. By subtracting the function  $G_z$  from the observed gravitational field, we obtain an anomaly which is governed by the top of the Bukharskiye limestones and the underlying density boundaries. In the next stage it is necessary to get rid of the influence of boundaries situated below the Bukharskiye deposits.

The proposed method for excluding the influence of the Quaternary deposits was compared with direct computations, since the position of the bottom of the unconsolidated formations for the cited structure (see Fig. 2) is approximately known. The influence of Quaternary deposits was excluded by means of averaging. A comparison of the results of exclusion of the influence of the upper part of the section by means of computation of the function  $G_z$ , averaging and direct computations indicated that the difference between them does not exceed 15%. The most local anomaly from the unconsolidated deposits is not great in intensity (up to 1.5 mgal), so that such a discrepancy in the subsequent interpretation is acceptable, taking into account, at any rate, that the survey accuracy is  $\pm 0.2$  mgal, whereas the intensity of the anomaly from the structure is about 10 mgal.

It should be noted that the time expenditures on computation of the  $G_z$  function is not greater than in the case of ordinary transformations, since the entire computation process is reduced to the use of one quadrature formula. This formula is such that the regional background to the second degree inclusive is excluded automatically.

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An exclusion of the influence of the lower density discontinuities was also accomplished by computing the  $G_z$  function. It is known from geological data that the maximum depth of burial of the Bukharskiye limestones is approximately 4 km. The  $G_z$  function was computed relative to a profile situated at a depth of 4 km (see Fig. 1).

After computing the  $G_z$  function, we obtained a solution of the inverse problem of the contact surface of the Bukharskiye limestones on the basis of the  $G_z$  distribution. As is well known, the initial formula for  $G_z$  has the following form [3]:

$$G_z(x, 0) = \frac{1}{\pi} \int_{-\infty}^{\infty} \mu(\xi) \frac{h^2 - (x - \xi)^2}{[(x - \xi)^2 + h^2]^2} d\xi, \quad (1)$$

Here  $\mu(\xi) = 2\pi f \sigma H(\xi)(h_2 - h_1)$ ;  $h$  is depth to the profile  $A - A$  (equal to 4 km), for which the function  $G_z$  was computed;  $H(\xi)$  is the deviation of the contact surface relative to the mean depth  $h$ ;  $h_2 = h + \Delta$ .

We will transform formula (1) to the following form:  $h_1 = h - \Delta$ , where  $\Delta$  is half the distance between the mean depths  $h_1, h_2$  of the symmetric contact discontinuities  $H(\xi)$

$$G_z(x, 0) = \frac{1}{\pi} \int_{-\infty}^{\infty} \mu'(\xi) \frac{h}{(x - \xi)^2 + h^2} d\xi, \quad (2)$$

where

$$\mu'(\xi) = \mu(\xi) \frac{h^2 - (x - \xi)^2}{h[(x - \xi)^2 + h^2]}.$$

Thus, solution of the problem for a double layer led to solution of the inverse problem for one layer. Accordingly, for solution of equation (2) it is possible to use the quadratic formula from [1]. The formula is simple, requires a minimum of time expenditures on computations and gives satisfactory results when there are not excessively great dips of the contact surface, when there are no sharp twists, faults, etc. on it. The numerical integration interval was 0.5h. After finding the  $\mu'(\xi)$  distribution, for any arbitrary point it can be assumed that  $x = 0$  and  $\xi = 0$ , since we have a choice of the origin of coordinates when  $\mu'(\xi) = \mu(\xi)/h$ . In this case the deviations  $H(\xi)$  must be taken relative to the mean depth  $h_1$ , which is equal to 3 km.

The mean weighted excess density of the multilayer section of Quaternary, Neogene and Upper Paleogene deposits relative to limestones of the Bukharskiy stage is difficult to find and therefore for a more precise determination of the deviations of the contact surface  $H(\xi)$  from the mean depth we will proceed in the following way. We will determine the mean weighted density in the region of the arch of an anticlinal fold, where the deviation of the contact surface is known precisely on the basis of drilling data. In our case the excess density was  $+0.34 \text{ g/cm}^3$ , which very satisfactorily corresponds to real conditions. For determining  $H(\xi)$  it is possible to use the following ratio [1, 2]:

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$$H(\xi_i) = H_{\text{CMB}} \frac{\mu(\xi_i)}{\mu_{\text{CMB}}}, \quad (3)$$

[CMB = bore(hole)] where  $H_{\text{bore}}$  is the deviation of the contact surface from the mean depth in the borehole;  $H(\xi_i)$  is the deviation of the contact surface at an arbitrary point;  $\mu_{\text{bore}}$  and  $\mu(\xi_i)$  are the values of the double layer, obtained after solution of equation (1).

The results of determination of the contact surface using formula (3) are presented in Fig. 1 (marked by crosses). As a result, we see a satisfactory agreement of the determined contact surface by the proposed method with data from drilling and other geophysical methods, except those sectors where there are tectonic dislocations. In the region of anticlinal structures, for which drilling data were available, we computed the error in determining the contact surface, which did not exceed 15%. The determined accuracy for practical purposes is acceptable for such a complex multilayer geological section. For synclinal zones it is extremely difficult to evaluate the accuracy of the constructions because the top of the Bukharskiy stage is not known precisely. The error in constructing the contact surface by the usual method leads not only to a considerable quantitative error (up to 25%), but also to qualitative errors (for example, according to the observed field the structure looks two-humped).

A solution of the integral equation (1) is possible in a somewhat different way. Since the  $G_z$  function describes the difference anomaly from two identical contact surfaces, one of which is situated considerably lower and its contribution to the total field is less, then in the first approximation it can be assumed that the  $G_z$  function is created only by the upper contact surface. Then the inverse problem is solved extremely simply. After solution the determined surface density values are placed at the depth of the second contact surface. Having the distribution of surface density at the level of the mean depths of the upper and lower contact surfaces, using analytical continuation from each mean depth to the observation surface and the subsequent results of the continuation we compute the function  $G'_z$ . If the function  $G'_z$  does not coincide with the initial  $G_z$ , we find the difference between them and we repeat the process of determining the contact surface. As shown by computations with theoretical models, one approximation is usually adequate. It should be noted that the second approach for solution of the equation is preferable, since testing with models confirms this (see Fig. 1, denoted by dots).

Also employed was the method for determining a contact surface under the condition that excess density is unknown. This method is similar to that given in [3]. For this purpose, using the distribution of the  $G_z$  function, we computed the vertical derivative  $G_{zz}$  and found the ratio of these functions

$$H(x, 0) = \frac{G_z(x, 0)}{G_{zz}(x, 0)}. \quad (4)$$

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The ratio  $R(x, 0)$  has the dimensionality of length.

Since the sense and purpose of the  $R(x, 0)$  value are completely similar to the same value from [3], the entire difference between them will be only in the mathematical computations. We will write a final formula making it possible to express the deviation of the contact surface from the mean depth through the  $R(x, 0)$  value

$$H(\xi) = h \frac{h-2R}{h-3R} \quad (5)$$

But this procedure, although it gave satisfactory results in the theoretical examples, in the specific case gives only qualitative results. The curve  $R(x, 0)$  itself correlates very well with the surface of the Bukharskiye layers, but the amplitudes of the uplifts are less by a factor of almost 2. This is evidently associated with the systematic error in computing the function  $R(x, 0)$ .

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GEOPHYSICS, ASTRONOMY AND SPACE

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AUTOMATION OF COMPUTATIONS OF GRAVITATIONAL INFLUENCE OF LOCAL RELIEF

Moscow PRIKLADNAYA GEOFIZIKA in Russian No 89, 1977 pp 96-104

[Article by A. A. Chernov]

[Text] Virtually all stages in processing of the results of gravimetric measurements have now been automated, both in the form of individual programs and in automated processing systems (complexes) [3, 6]. The programs, complexes and systems differ with respect to the methods and algorithms for solution of different problems and also with respect to organization of the computations process. Different technologies for automating the computation process ensure a different level of automation of computations and the use of different algorithms for solution of processing problems determines the attainable computation accuracy and also the breadth or the range of modifications and variants of the problem.

In virtually all such developments the automation of computations leads to an increase in the accuracy of processing and a marked reduction in the expenditures of manual labor. The only exception is the procedure for taking into account the influence of the surrounding terrain, although this problem was solved as one of the first in the processing of gravimetric exploration data. Widely known and successfully used in practical work are the programs prepared using the algorithms formulated by O. K. Litvinenko, V. V. Lomtadze, L. A. Koval' and many others [4, 6]. Despite the great number of different programs, making it possible to carry out computations of corrections for the points of intersection in a regular grid and directly for gravimetric points, the degree of automation of solution of this problem still remains obviously unsatisfactory.

The real accuracy in computing corrections for relief is too low and the expenditures on manual work are so great that the profitability of use of electronic computers in this case is frequently in doubt. All the methods and programs which have been developed and used in practical work assume the stipulation of digital terrain models (DTM), which requires significant expenditures of manual work. On this to a definite degree is also dependent the relatively low accuracy in computations, since the elevations of the gravimetric stations and the elevations of the digital terrain models are determined by different methods and in a general case do not correspond to one another.

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Under conditions of sharply dissected mountain relief the influence of the near (central) zone is taken into account, as a rule, manually, since computations on an electronic computer require the stipulation of DTM with a small interval (50, 100 m); this leads to an increase in the expenditures on manual work and inevitably reduces the accuracy in the representation of relief. In addition, there are not always maps of the required scale. The methods employed in aerial photogrammetry and also correction meters do not solve the problem: when the terrain is forested, when there are no aerial photographs and with the limitations on the effective zone of the correction meters there is a narrowing of the range of their applicability.

The modern method for computing the influence of relief using electronic computers involves a definite paradox: the elevations, representing relief, are taken from the maps (with relatively great errors), whereas the elevations of the gravimetric stations, determined with considerably higher accuracies, are not used in creating a digital terrain model. The taking of the DTM from topographic maps using an overlay generates not only random errors in interpolation and copying, but also involves an error in drawing the isohypses.

The use of the elevations of gravimetric stations, determined with a high accuracy, promises not only a reduction in the expenditures of manual labor on the preparation of data, but also an increase in the accuracy of computations, in the process of creating digital terrain models. Since the gravimetric stations are usually situated in a relatively narrow hypsometric interval of mean elevations, for the representation of relief it is also necessary to employ extremal elevations, that is, the characteristic relief points, which are trigonometric stations, peaks, elevations of river channels, etc. It is obvious that the number of characteristic points in the relief, taken additionally from the topographic maps, should vary considerably in dependence on the complexity of relief, the peculiarities of the survey network, etc.

The computation of the influence of relief in the central zone in this case is accomplished by means of analytical integration. The influence of relief is determined in the following way:

$$[\rho = \text{relief}] \quad \Delta \epsilon_p = f \sigma \int_{-A}^A \int_{-B}^B \int_0^H \frac{h(x, y) dx dy dz}{[x^2 + y^2 + h^2(x, y)]^{3/2}}, \quad (1)$$

where  $f$  is the gravitational constant,  $\sigma$  is the density of surface rocks.

After integration for  $h$  and expansion of the integrand using a binomial formula, taking into account the first two terms of the expansion, the expression for the correction assumes the following form [1]:

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$$\Delta H_p = H_0 \int_A^A \int_B^B \frac{H^2 dx dy}{(x^2 + y^2)^{3/2}} - H_0 \int_A^A \int_B^B \frac{(H_1 - H_0)^2}{(x^2 + y^2)^{3/2}} dx dy, \quad (2)$$

where A, B are the integration limits (that is, zones in which relief is taken into account),  $H_0$  is the elevation of the computation point;  $H_1$  is the elevation of the "current" relief point. A series of approximate methods for computing the corrections for relief [4] is based on use of expression (2).

With the stipulation of  $H(x, y)$  by some function, such as a power-law polynomial, the integral (2) is easily obtained analytically. The procedure which we described was realized for polynomials of second and third degrees and therefore the value of the correction is expressed through the coefficients for a polynomial approximating relief and the coordinates of gravimetric stations relative to the center of coordinates. The program for applying the method is written in ALGOL-60 language applicable to the TA-2m translator; it is based on the method and program for polynomial interpolation developed earlier by the author in collaboration with P. A. Besprozvanny [2]. In this method use is made of the approximation of an interpolated surface (field) in a "moving window" of variable size by a power-law polynomial of an automatically changeable degree. The approximation is made by the least squares method with weighting of the nonclosures for the distances of the points of stipulation of the initial function from the interpolation point, coinciding with the center of the "window" (grid).

$$\Phi = \sum_{i=1}^N \delta_i^2 \rho_i \rightarrow \min, \quad (3)$$

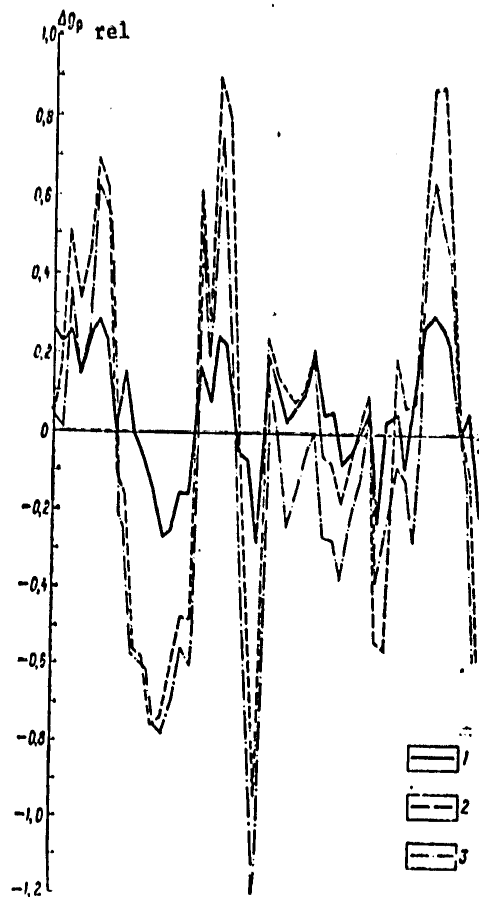
where  $\delta_i = z_i - u_i$  is the deviation of the approximating function  $z$  from the value of the initial function  $u$ ;  $N$  is the number of points in the grid. The weight of the nonclosure  $\rho_i$  is selected in accordance with the recommendations of M. La Porte [6] in such a way that at the center of the window it is equal to unity and at the edge is equal to zero:

$$\rho_i = \left(1 - \frac{r_i^2}{2n^2}\right)^n.$$

The degree of the approximating polynomial is selected automatically in dependence on the number of points entering into the grid and in such a way that the number of coefficients  $n$  with the selected degree of the polynomial  $M$ , equal to  $n = [(M+1)(M+2)]/2$ , is the closest from below to the number  $N$  of points in the grid. The described approach to solution of the problem ensures an insignificant smoothing with the use of not excessively high degrees of the approximating polynomials [2-6]. The smoothness of the interpolated field (surface) is achieved by a considerable overlapping of adjacent grids in combination with the smoothness of the polynomial and a bell-like form of the weighting function. Stability of the solution is ensured by procedures improving the conditionality of the system of normal equations relative to the coefficients of the approximating polynomial;

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Graphs of differences in corrections for relief computed using digital terrain models obtained by means of automatic interpolation relative to corrections obtained with manual processing of digital terrain models. Interpolation with use of: 1) 2,900 characteristic relief points; 2) 2,300 points; 3) 1,450 points

the first step is the procedure of rejecting of the equations corresponding to coefficients not supported by the arrangement of initial points.

The described interpolation algorithm can be used for obtaining digital terrain models on the basis of arbitrarily situated gravimetric stations and characteristic relief points. The simplified computations which we made

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earlier indicated that this method ensures reliable reproduction of the DTM when the ratio of the initial and the resultant points is 1:4 [7]. Since the elevations and the coordinates of the gravimetric points must be coded regardless of the method for computing the influence of relief, and also for subsequent processing on an electronic computer, the proposed method will be economically justified with a ratio of the number of initial characteristic points in the relief to the number of DTM points of 1:3 or lower.

The semiautomatic coder produced at the present time by the "Kazgeofizpribor" plant on a practical basis makes it possible to prepare the coordinates of the points plotted on topographic maps directly on a machine carrier with negligible work expenditures. Thus, the use of a coder for the coding (and readout) of the characteristic relief points considerably simplifies the introduction of the proposed method and makes it profitable even with higher values of the indicated ratio.

A determination of the minimum necessary number of characteristic relief points is evidently a key problem in the proposed method. It is also evident that the interpolation of relief is a problem which is incomparably more complex than the interpolation of potential fields because relief is not a smooth function. But in this case as well there is no need to obtain a relief model identical to the real relief; it is only necessary to maintain an equality of the volume integrals from the real relief and the created models. The latter circumstance is very important because the precise recreation of relief with scarps and high-rising crags is impossible when using interpolation procedures.

In order to test the proposed method and determine the influence of the number of characteristic relief points on the results of the computations we carried out experimental computations with the use of practical materials for the mountainous regions of Armenia and Georgia. We used a sector measuring 35 x 45 km, characterized by a variation of elevations from 800 to 3,200 m. In this sector a DTM with an interval of 0.5 km was prepared manually. From topographic maps we read 2,900 characteristic relief points, taking into account the arrangement of gravimetric points; the latter were located in the selected sector for the most part in the central area, whereas the "edge" with a width of 10 km was virtually not supplied with them and this greatly increased the total number of points used.

The elevations and coordinates of the characteristic relief points and gravimetric stations constituted the initial data for the described interpolation program, by means of which it was possible to compute a DTM (corresponding to the manual model) consisting of 6,500 points of a regular grid. The initial ratio of the number of additional and resultant points was approximately 3:7, but with a maximum thinning of the additional points -- less than 1:4. The initial number of additional characteristic points was successively thinned by 25, 33 and 50%; each time interpolation was then carried out and corrections were computed. In computing the

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corrections in all cases use was made of a program worked out in the Geology Faculty Moscow State University [5]. The corrections were computed in the zone from 1 to 10 km.

Table 1

Число характерных точек рельефа, учтенных при интерполяции 1	Среднеквадратичное отклонение $\Delta g_p$ , мгал 2	Среднее отклонение $\Delta g_p$ , мгал 3
2000	0.1420	-0.0021
2320	0.1384	-0.0287
1930	0.1410	-0.0205
1450	0.1600	-0.0102

## KEY:

1. Number of characteristic relief points taken into account in interpolation
2. Standard deviation  $\Delta g_{rel}$ , mgal
3. Mean deviation  $\Delta g_{rel}$ , mgal

Table 2

Функция 1	Теоретическое значение $\Delta g_p$ 2	Значение $\Delta g_p$ , полученное по программе 3
4 Эллипсоид $\frac{x^2+y^2}{10^4} + \frac{(H-102.5)^2}{192.5^2} = 1$	0.3134	0.2684
5 Конус $H = \frac{1}{5}\sqrt{x^2+y^2}$	0.1650	0.2237
6 Гиперболические параболоиды $H = \frac{y^2-x^2}{100}$	0.1368	0.1365
$H = \frac{y^2-x^2}{25}$	2.1900	2.1650
7 Эллиптические параболоиды $H = \frac{x^2-y^2}{100}$	0.3480	0.3478
$H = \frac{x^2-y^2}{400}$	0.2178	0.2173
8 Примечание. Пределы интегрирования 0-45 м.		

## KEY:

1. Function
2. Theoretical value  $\Delta g_{rel}$
3.  $\Delta g_{rel}$  value obtained under program
4. Ellipsoid
5. Cone
6. Hyperbolic paraboloids
7. Elliptical paraboloids
8. Note. Integration limits 0-45 m

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Table 3

Исправлен $\Delta g_{rel}$ , мгал, 1		Разность поправок $\Delta g_{rel}$ , мгал	Исправлен $\Delta g_{rel}$ , мгал, 1		Разность поправок $\Delta g_{rel}$ , мгал
причины 2	по програм-ме 3		причины 2	по програм-ме 3	
0.12	0.15	0.03	0.30	0.20	0.04
0.10	0.09	0.01	0.11	0.04	0.07
0.65	0.66	0.01	0.60	0.63	0.03
0.32	0.27	0.05	0.03	0.86	0.07
0.60	0.68	0.01	0.66	0.72	0.06
0.60	0.66	0.06	0.14	0.14	0.00
0.32	0.23	0.09	0.33	0.33	0.00
0.05	0.10	0.05	0.28	0.34	0.08
0.06	0.03	0.03	0.42	0.40	0.07

## KEY:

1. Corrections  $\Delta g_{rel}$ , mgal, computed
2. manually
3. under program
4. Difference in corrections  $\Delta g_{rel}$ , mgal

The results are given in Table 1 and are partially represented in the figure. The values of the mean discrepancies in the corrections, computed using manual and interpolated DTM, show that these discrepancies are random. The relatively high value of the maximum deviation 0.3 mgal does not seem excessive because such results are obtained in computations on the basis of an independently prepared manual DTM. The standard deviations (Table 1) also do not exceed the errors in computing corrections in the middle zone by traditional methods (under conditions of sharply dissected mountainous relief).

For the proper evaluation of the effectiveness of the proposed method it is necessary to take into account that for testing use was made of a sector of insignificant area in which the "useful" part, occupied by processable gravimetric stations, was 20%; the remainder was the necessary "edge," ensuring allowance for the influence of relief with the required radius. In practical computations this "edge" occupies no more than several percent of the DTM.

The program for computing the influence of relief in the central zone was tested using models and a practical example. The computations made using hyperbolic and parabolic paraboloids, an ellipse and cone as models, made it possible to evaluate accuracy and demonstrate the applicability of the developed model (Table 2). The discrepancies in the theoretical value of the corrections and those computed using the described program were: for ellipsoids -- about 0.03 mgal, cones (the most unfavorable for approximating bodies by paraboloids) -- 0.06 mgal, parabolic and hyperbolic paraboloids -- virtually equal to zero.

Practical testing was carried out in a sector of real relief (map scale 1:10,000). The results of computations, made for 18 points, are given in Table 3. It can be seen that the corrections, computed using the program

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and manually employing a Lukavchenko grid, do not exceed 0.1 mgal, averaging 0.04 mgal, or 11% of the mean value of the corrections.

Thus, we have proposed a method for computing the influence of relief based on use of the elevations of gravimetric stations and characteristic relief points and employing a polynomial approximation method [7]. For computing the corrections in the central zone a program was prepared for direct computation of these corrections by the analytical integration method. The program was tested using model and practical examples.

For computing the influence of relief in the middle and distant zones it has been proposed that use be made of a program for areal interpolation for creating a DTM, using which the corrections are computed by traditional methods. Using practical material it was demonstrated that the proposed method can be used and is profitable.

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GEOPHYSICS, ASTRONOMY AND SPACE

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RESULTS OF SEA TESTS OF GMN-K AUTOMATED GRAVIMETERS

Moscow PRIKLADNAYA GEOFIZIKA in Russian No 89, 1977 pp 104-110

[Article by V. O. Bagramyants]

[Text] Modern surface sea gravimeters, intended for investigations of shelf regions and coastal zones, are for replacement of bottom gravimeters with a low productivity. For this purpose the accuracy in measurements with surface gravimeters must be  $\pm 0.5 + 1.0$  mgal with disturbing accelerations up to 50-100 gal.

The GMKP sea quartz spring gravimeter, developed at the All-Union Scientific Research Institute of Geophysics, during tests revealed good possibilities for its use for geological prospecting purposes. On short runs on a vessel with a displacement of 100 tons the attained measurement accuracy was about  $\pm 0.8-1.0$  mgal [2].

As a result of improvement of the GMKP gravimeter it was possible to produce an automated sea surface quartz gravimeter (GMN-K), supplied, the same as the GMKP, with a gyropendulum stabilizer [4].

Sea tests of different types of sea gravimeters, including the GMN-K, made it possible to evaluate the accuracy characteristics of the gravimeters and to compare them with one another.

The tests were carried out aboard the hydrographic ship "Dmitriy Laptev" with a displacement of 1,600 tons, outfitted with modern navigational equipment. In the course of the tests the ship's coordinates were determined using a "High Fix" radiogeodetic system, ensuring determination of the Bötvs corrections with an error not greater than  $\pm 0.5-0.8$  mgal.

The processing of all the collected data was accomplished using "Minsk-22" electronic computers with use of the "Kompost" program [3]. This article gives the principal results of the tests.

The surface gravimetric apparatus outfit used in the tests consisted of three GMKP spring quartz gravimeters No 4 and two automated instruments GMN-K No 1 and GMN-K No 5. The GMN-K and GMKP gravimeters have a similar

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design. The difference is that the GMN-K elastic system has an additional narrow-range measuring compensation system ensuring operation of the instrument in an automatic regime without restructuring in the range of gravity changes 800-1000 mgal.

In order to eliminate autooscillations for improving the dynamic characteristics the GMN-K instrument also contains a special device for introducing into the closed regulation system a correcting signal which is proportional to the time derivative of the mismatch signal. More detailed information on the design of the gravimeters is given in [1, 2]. The GMN-K gravimeter, the same as the GMKP, is calibrated quite reliably by the tilt method.

The analog registry of the readings of all three instruments was accomplished using one 12-point automatic recorder of the KSP-4 type. In addition to the electric signals corresponding to the position of the pendulums and turns of the compensation microscopes, for monitoring the operation of the thermostats there was also registry of the temperatures within the gravimeters.

The gravimeters were placed in a room (cabin) on the lower deck at a distance of 10 m from the ship's metacenter. In order to reduce the errors in the gyrostabilizers due to the ship's tilts the instruments (GMN-K) were suspended on supports in auxiliary Cardan suspensions. The pendulum of the GMN-K gravimeter elastic system (GMN-K No 1) was oriented along the longitudinal axis of the ship, and for excluding the cross-coupling effect the pendulums of the gravimeters GMKP No 4 and GMN-K No 5 were directed in the opposite direction.

Gravity determinations at bottom stations were made using two standard GDK gravimeters. The working method and accordingly the test program were organized in such a way that, first, to determine the influence of disturbing factors on operation of the GMN-K gravimeters and in comparison with synchronously executed bottom gravimetric observations, evaluate the accuracy of the surface measurements; second, to carry out an areal survey in an ocean area, using a system of bottom stations as a reference network.

Observations with surface gravimeters were made continuously during the entire run, lasting about 40 days, both while the ship was on course and when at anchor. Course observations were made at a speed of 13-13.5 knots with continuous operation of the automatic rudder. Using data from the radionavigation system (accuracy in determining coordinates  $\pm 80-100$  m) each six minutes the position of the ship on the profile was determined and in the event of its drift the course was corrected. In order to reduce the error in operation of the gyrostabilizers caused by rotational movements of the ship, the changes in course were no more frequent than once per minute and constituted not more than  $1^\circ$ .

Surface measurements were made with sea waves up to class 3-4 (less frequently up to 5); the amplitude of vertical accelerations on the average did not exceed 40-50 gal. On some profiles with a deterioration of

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meteorological conditions the vertical accelerations attained 100 gal or more, but the horizontal accelerations did not exceed 40-50 gal.

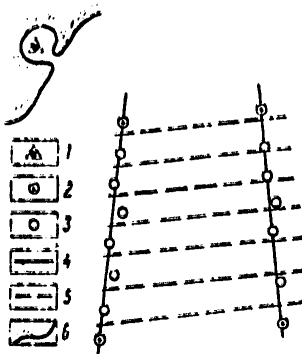


Fig. 1. Diagram of location of surface and bottom stations in ocean area. 1) principal control point; 2) bottom control point on profile; 3) bottom regular point; 4) surface control profile; 5) surface regular profile; 6) shoreline

Table 1

Номер гравиметра	Время наблюдений	Смещение нуль-пункта, мгг/сут	Средне-квдратиче- ская ошибка единич- ных наблюдений, мгг
1	2	3	4
5 ГМН-К № 1	2.VII-28.VII	1,48	$\pm 2,1$
	28.VII-11.VIII	1,01	$\pm 2,0$
ГМН-К № 5	2.VII-20.VII	0,38	$\pm 1,9$
6 ГМКП № 4	2.VII-11.VIII	0,50	$\pm 2,3$

## KEY:

1. Number of gravimeter
2. Observation time
3. Null-point displacement, mgal/day
4. Mean square error in individual observations, mgal
5. GMN-K
6. GMPK

At the anchor stations the measurements were made simultaneously with the GMN-K and the GDK; such surface observations were successful in all cases except for those when the rate of the ship's oscillations was more than 3-5 degrees/minute.

Gravimetric observations in the survey area were made in the following way. The entire area was broken down into approximately rectangular sectors with sides not longer than 100 km. Ordinary (regular) underwater observation profiles, spaced 8-10 km apart, rested on surface control profiles (CP), whereas the latter rested on bottom control gravimetric points (BCGP). In addition, along the CP a system of additional bottom points (BGP) was inserted,

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resting on the BCGP, which were used in evaluating the accuracy of operation of the sea gravimeters. The surface and bottom observations were tied in to a single main control point (MCP), situated in the bay, protected against sea waves (Fig. 1).

In the course of the sea tests a network of bottom points (stations) was established. It consisted of 8 BCGP and 28 BGP, 14 CP (some of which were processed more than once) and a regular network of 22 profiles with a total length of about 3,000 km. The area of the gravimetric survey was about 30,000 km<sup>2</sup>.

The stability of instrument operation was evaluated using the results of repeated measurements at the MCP. These observations were made not less frequently than each 7-10 days; the duration of each stop was 1-1.5 days. The values of the null-point shifts and the standard deviations of individual observations with each instrument relative to the straight line approximating the linear component of null-point shift, computed on the basis of these data, are presented in Table 1.

The accuracy of sea observations while the vessel was on course was evaluated both on the basis of the internal convergence of the instruments and on the basis of external convergence, on the basis of the coincidence of measurements on repeated runs, at the points of intersection of the survey and control runs, and finally, on the basis of a comparison with the bottom values of gravity, registered using the GDK.

Evaluations of measurement accuracy with respect to internal convergence between instruments on each run were made using the formula

$$m_1 = \pm \frac{1}{3} \sqrt{\frac{\sigma_{1-5}^2 + \sigma_{1-4}^2 + \sigma_{5-4}^2}{2}},$$

where  $\sigma_{1-5}$ ,  $\sigma_{1-4}$ ,  $\sigma_{5-4}$  are the dispersions of the differences between the paired readings of two gravimeters (the subscript gives the numerical designations of the gravimeters).

These values are computed on an electronic computer in the course of data processing. For control profiles the  $m_1$  value averaged  $\pm 0.6$  mgal, for ordinary profiles --  $\pm 0.8$  mgal.

The accuracy of measurements with respect to external convergence was evaluated using the formula

$$m_2 = \pm \sqrt{\frac{\sum \Delta_i^2}{2n}},$$

where  $\Delta i$  is the difference in the observed  $\Delta g$  values, mgal;  $n$  is the number of compared points.

In a comparison of the results of measurements on repeated runs ( $n = 34$ ) the  $m_2$  value was found to equal  $\pm 0.9$  mgal, and in a comparison at the points of intersection of survey and control runs it was  $\pm 1$  mgal. The results of comparison with bottom measurements are of the greatest interest (Table 2).

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According to data cited in Table 2, it was found that  $m_2 = \pm 1.2$  mgal with  $n = 22$ .

Table 2 shows that the accuracy of observations  $\Delta$  on profile 939 was appreciably lower than on the remaining profile, which can be attributed to the presence of marked changes in the directions of the ship along the profile; these were carried out for the purpose of the most precise passage over previously placed bottom stations. In those cases when the bottom points were established after carrying out surface measurements along linear profiles, the comparison indicated a substantial increase in accuracy. For example, on profile 965, worked in such a way (Fig. 2), the error in surface measurements  $m_2$  is evaluated at  $\pm 0.65$  mgal, without taking into account the error in bottom measurements, and  $\pm 0.5$  mgal when they are taken into account.

Table 2

	ДГП A	Номер галса (профиля) B	$\Delta = \Delta g_{\text{надб}} - \Delta g_{\text{дон}}$ мгг C
D	ДГП-10	981 918	-0.9 -0.7
	ДГП-2	939 993	0.0 -1.9
	ДГП-4	939 993	+1.7 -2.4
	ДГП-6	939 993	+2.0 -1.2
E	ДГП-7	993 939	+0.2 -1.6
	ДГП-9	907	+0.5
	ДГП-10	907	+0.9
	ДГП-11	907	+0.8
	ДГП-12	907	+0.2
	ДГП-В	907	+0.2
	ОГП-7	907	-1.9
	ДГП-24	965	-0.9
	ДГП-27	965	+1.1
	ДГП-28	965	+0.3
	ДГП-29	965	+0.3
	ДГП-23	965	+0.1
	ДГП-22	965	-0.7
			$\Delta_{\text{ср}} = -0.2$ мггг F

## KEY:

- A) BGP
- B) Number of run (profile)
- C)  $\Delta = \Delta g_{\text{surf}} - \Delta g_{\text{bot}}$ , mgal
- D) BGP
- E) MCP
- F)  $\Delta_{\text{mean}} = -0.2$  mgal

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The results of observations at anchor stations, which were made simultaneously with bottom measurements, are of definite interest. Table 3 gives comparisons of such observations made along the profile "CP-7." The very same point, BCGP-7, serves as a control point for both surface and bottom observations.

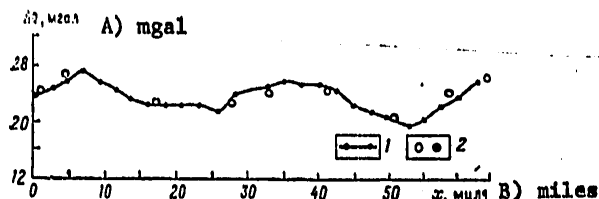


Fig. 2. Comparison of surface and bottom observations on profile. 1) surface determinations with GMN-K; 2) bottom determinations. A) mgal; B) miles

Дата наблюдений 1	Время, ч-мин 2	Обозначение пункта 3	Глубина, м 4	$\Delta g_{\text{над}} - \Delta g_{\text{дон}}$ , мгал 5
14.VII	11-30	7 ДОГП-7	40	0.0
	14-00	8 ДГП-10	37	-0.3
	16-00	ДГП-8	37	+0.6
	18-00	ДГП-9	32	+0.1
15.VII	02-00	ДГП-13	74	-1.2
	03-15	ДГП-12	75	-0.1
	04-50	ДГП-11	61	+0.5
	06-50	ДОГП-7	40	0.0
				$\Delta_{\text{ср}} = -0.1$ мгал 6

KEY:

- 1) Date of observations
- 2) Time, hours-minutes
- 3) Designation of station
- 4) Depth, m
- 5)  $\Delta = \Delta g_{\text{surf}} - \Delta g_{\text{bot}}$ , mgal
- 6)  $\Delta_{\text{mean}} = -0.1$  mgal
- 7) BCGP
- 8) BGP

Table 4

Номер гравиметра 1	Число пунктов сравнения 2	Погрешность измерений, мгал 3	
		систематическая 4	среднеквадратическая 5
6 ГМН-К № 1	30	-1.2	$\pm 2.4$
ГМН-К № 5	22	+0.5	$\pm 2.7$
7 ГМКП № 4	30	-2.0	$\pm 3.5$

KEY:

- 1) Number of gravimeter
- 2) Number of comparison points
- 3) Measurement error, mgal
- 4) Systematic
- 5) Mean square
- 6) GMN-K
- 7) GMPK

Taking into account the error ( $\pm 0.4$  mgal) in the values of bottom determinations, reduced to sea level, the conclusion can be drawn that there is an approximate equal accuracy of both measurements. However, it must be noted that these observations were made when waves at sea were not more than

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class 2-3, and the disturbing accelerations did not exceed 20-30 gal.

The estimates cited above were made for quite short runs with an average duration of 5-6 hours. The tie-in of regular surface profiles with sea control points (profiles) makes possible a partial compensation of the possible systematic errors caused by the influence of disturbing accelerations and ship tilts, especially the cross-coupling effect. In this connection it is of considerable interest to compare the sea observations (on course) in a long run with bottom observations.

Using the control observations, after taking into account the corrections for null-point shift, in accordance with the data in Table 1, for each of the surface gravimeters (on course), we computed the  $\Delta g$  values over bottom points and carried out their comparison, the results of which are given in Table 4.

The GMN-K instruments were more precise than the GMKP instruments. However, the averaging of the readings for the GMN-K gravimeters for the purpose of lessening the influence of the cross-coupling effect, and also the random errors, did not lead to a significant increase in measurement accuracy. The mean square error for the three instruments was  $\pm 2.3$  mgal (systematic component -- 1 mgal) and proved to be only a little different than the error in measurements with the GMN-K No 1 ( $\pm 2.4$  mgal). This is attributable, first of all, to the insignificant CC influence (in comparison with the total error) and second, to the presence of significant systematic errors, the influence of which is not excluded with averaging.

If it is assumed that the errors  $\epsilon_1$ , caused by the instability of each gravimeter, were determined (see Table 1) using the results of repeated MCP observations, it is possible, excluding them from the total error  $\epsilon$ , to estimate the magnitude of the errors  $\epsilon_2$  caused by the influence of disturbing accelerations and the ship's tilt, and also the Eötvös effect. For the GMN-K No 1, GMN-K No 5 and GMN-K gravimeters the  $\epsilon_2$  values were  $\pm 1.2$ ,  $\pm 1.9$  and  $\pm 2.7$  mgal respectively.

The following conclusions can be drawn from everything said above.

Our tests indicated that the GMN-K gravimeters on runs with a duration greater than 30 days with disturbing accelerations of about 50 gal ensure measurement of gravity with an error not greater than  $\pm 2.5$  mgal. Accordingly, without a special network of bottom control points it is possible to carry out a survey with isoanomalic lines drawn each 5-10 mgal.

On short profiles, with a length of about 100 km, resting on sea bottom control points, the GMN-K instrument can ensure measurements of gravity increments with an error  $\pm 0.5$ - $0.6$  mgal. Thus, the joint carrying out of surface and bottom observations makes it possible to carry out an areal survey and compile maps at a scale 1:200,000 with isoanomalic lines drawn each 2 mgal.

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For a further increase in the accuracy of sea surface measurements it is necessary to increase the accuracy and stability of operation of the gravimeters and the gyrostabilizers and also the accuracy in determining the corrections for the influence of accelerations arising during the movement of the vessel (Eötvös effect, cross-coupling effect, etc.).

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METHOD FOR DETERMINING THE SECOND DERIVATIVES OF GRAVITATIONAL POTENTIAL  
ON A MOVING BASE

Moscow PRIKLADNAYA GEOFIZIKA in Russian No 89, 1977 pp 111-115

[Article by G. O. Krylov and I. I. Naumenko-Bondarenko]

[Text] At the present time both in the USSR [1-3, 5-7] and abroad [8, 9] studies are being made of the possibility of obtaining the second derivatives of gravitational potential on a moving base. This will make it possible to increase the productivity of variometer measurements. In addition, information on the second derivatives of gravitational potential is necessary in solving problems related to the theory of figure of the earth, in exploratory geophysics and in navigation.

When making measurements on a moving base to determine the second derivatives of gravitational potential, the same as in the registry of the first derivatives, the need arises for discriminating the useful signal against the noise background. In discriminating the first derivative against the background of inertial accelerations, the basis used is the frequency method for the separation of the signal from the noise. The strength of the useful gravitational signal is tens of thousands of times less than the noise and therefore the discrimination of the signal against the noise background presents considerable difficulties.

The situation is different when measuring the second derivatives in movement. The sensor of second derivatives, like any other gravitational sensor, will be subject to the influence of inertial forces. However, for such a sensor the noise will be created for the most part by angular accelerations and to a lesser degree by the angular velocities of the base. With careful fabrication and balancing of the sensing element it should not react to linear accelerations.

We will assume that on a moving base information is obtained on the second derivatives of gravitational potential. In this case, as demonstrated in [4], from the second derivatives it is possible to form a second-rank tensor

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$$W_{ij} = \begin{bmatrix} W_{xx} & W_{xy} & W_{xz} \\ W_{yx} & W_{yy} & W_{yz} \\ W_{zx} & W_{zy} & W_{zz} \end{bmatrix},$$

where  $W_{xx}, \dots, W_{zz}$  are the measured values of the second derivatives.

The greatest noise is created by the angular accelerations. Even with such a small angular acceleration as  $10^{-6} \text{ sec}^{-2}$  noise is formed which is equal to 1,000 units. It would seem that the discrimination of a useful signal in the presence of such considerable noise would be as difficult as when measuring the first derivatives of gravitational potential.

However, this is not the case. There is an important peculiarity of the local gravitational and inertial fields -- a difference in the structure of the second-rank tensors. It appears that the tensor of angular accelerations is antisymmetric and the tensor of the second derivatives of gravitational potential is symmetric. Such a peculiarity of the fields makes it possible to separate the matrix formed from these derivatives into symmetric and antisymmetric parts and thus to filter out the noise caused by angular accelerations.

It should be noted that the components of the symmetric matrix are also dependent on the angular velocity of the base. For example, angular velocities of  $10^{-4} \text{ sec}^{-1}$  create noise of about 10 units. This noise can be filtered out if use is made of angular velocity sensors, by means of which it is now possible to measure angular velocities with an accuracy to  $10^{-6} \text{ sec}^{-1}$ . In addition, the noise level when measuring the second derivatives of gravitational potential can be decreased by means of placement of the sensors on a gyroplatform, free in azimuth.

Accordingly, when measuring the second derivatives of gravitational potential in movement the problem of contending with noise is solved completely and essentially even when there is a coincidence of the spectra of the useful signal and noise, which, as is well known, is impossible when measuring the first derivatives.

Now we will examine the possibility of separating the useful signal and noise when making measurements of the second derivatives.

For this purpose we will symmetrize the tensor  $W_{ij}$  obtained as a result of measurements using an algorithm with the transposed tensor  ${}^T W_{ij}$ :

$$W_{ij} = \frac{1}{2} (W_{ij} + {}^T W_{ij}) + \frac{1}{2} (W_{ij} - {}^T W_{ij}) = {}^s W_{ij} + {}^a W_{ij}.$$

Hence

$$W_{xx} = \frac{1}{2} (W_{xx} + W_{xx}) + \frac{1}{2} (W_{xx} - W_{xx});$$

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$$W_{xy} = \frac{1}{2} (W_{xy} + W_{yx}) + \frac{1}{2} (W_{xy} - W_{yx})$$

As a result of this operation, from the tensor  $W_{ij}$  we obtained two tensors -- symmetric  ${}_sW_{ij}$  and antisymmetric  ${}_aW_{ij}$ :

$${}_sW_{ij} = \frac{1}{2} (W_{ij} + {}_sW_{ji}) = \frac{1}{2} (W_{ij} + \omega_i \omega_j);$$

$${}_cW_{ij} = \frac{1}{2} (W_{ij} - \omega_i \omega_j) = \frac{1}{2} \begin{bmatrix} W_{xx} + \omega_y^2 + \omega_z^2 & W_{xy} - \omega_x \omega_y & W_{xz} - \omega_x \omega_z \\ W_{yx} - \omega_x \omega_y & W_{yy} + \omega_x^2 + \omega_z^2 & W_{yz} - \omega_y \omega_z \\ W_{zx} - \omega_x \omega_z & W_{zy} - \omega_y \omega_z & W_{zz} + \omega_x^2 + \omega_y^2 \end{bmatrix};$$

$${}_aW_{ij} = \frac{1}{2} (W_{ij} - {}_sW_{ji}) = -\dot{\omega}_{ij};$$

$${}_aW_{ij} = -\dot{\omega}_{ij} = \begin{bmatrix} 0 & \dot{\omega}_z & -\dot{\omega}_y \\ -\dot{\omega}_z & 0 & \dot{\omega}_x \\ \dot{\omega}_y & -\dot{\omega}_x & 0 \end{bmatrix},$$

[Initial subscripts: a = antisymmetric; c = s = symmetric]

where  $\omega_x, \omega_y, \omega_z$  are the components of the angular velocity vector;  
 $\dot{\omega}_x, \dot{\omega}_y, \dot{\omega}_z$  are the components of the angular acceleration vector.

The discrimination of the antisymmetric tensor is of interest when it is necessary to have information on angular accelerations; otherwise it is possible to limit ourselves to discrimination of the symmetric tensor. The operation of symmetrization makes it possible to filter out the errors caused by angular accelerations of the sensing element. After formation of the symmetric tensor  ${}_sW_{ij}$  it is necessary to filter out the errors caused by the angular velocities of the sensing element.

For this it is necessary to have information on the components  $\omega_x, \omega_y, \omega_z$  of the angular velocity vector and form the tensor

$$\omega_{ik}\omega_{kj} = \begin{bmatrix} -(\omega_y^2 + \omega_z^2) & \omega_x\omega_y & \omega_x\omega_z \\ \omega_x\omega_y & -(\omega_x^2 + \omega_z^2) & \omega_y\omega_z \\ \omega_x\omega_z & \omega_y\omega_z & -(\omega_x^2 + \omega_y^2) \end{bmatrix}.$$

Data for formation of the tensor  $\omega_{ik}\omega_{kj}$  can be obtained using two angular velocity sensors, whose planes of sensitivity are perpendicular.

The computation and formation of a second-rank tensor of gravitational potential is accomplished using the algorithm

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$$W_{ij} = \begin{bmatrix} W_{xx} & W_{xy} & W_{xz} \\ W_{yx} & W_{yy} & W_{yz} \\ W_{zx} & W_{zy} & W_{zz} \end{bmatrix} = {}^e W_{ij} + \omega_{ik} \omega_{kj} = \begin{bmatrix} W_{xx} & W_{xy} & W_{xz} \\ W_{yx} & W_{yy} & W_{yz} \\ W_{zx} & W_{zy} & W_{zz} \end{bmatrix} +$$

$$+ \begin{bmatrix} -(\omega_y^2 + \omega_z^2) & \omega_x \omega_y & \omega_x \omega_z \\ \omega_x \omega_y & -(\omega_x^2 + \omega_z^2) & \omega_y \omega_z \\ \omega_x \omega_z & \omega_y \omega_z & -(\omega_x^2 + \omega_y^2) \end{bmatrix}.$$

Thus, using a priori information on the measured parameter and noise, with registry on a moving base it is possible to obtain the values of the second derivatives of gravitational potential, free of noise caused by angular velocities and accelerations, even under the condition of a coincidence of their spectra.

The proposed method can be realized, for example, in the following way. Sensing elements are mounted on a gyroplatform, making it possible to measure all the second derivatives of gravity potential. In addition, this same gyroplatform carries two angular velocity sensors. They are placed in such a way that the planes of sensitivity of these sensors will be mutually perpendicular.

The readings of the sensing elements and angular velocity sensors are registered simultaneously. Then the tensors of the second derivatives of gravitational potential and angular velocities are formed from the readings of these instruments. After symmetrization of the second-rank tensor, which makes it possible to filter out the noise caused by the angular accelerations, the resulting symmetric tensor is summed with the tensor of angular velocities. As a result of these operations, we obtain the values of the second derivatives of gravitational potential, free of the noise caused by the angular velocities and accelerations.

The considered method for separating the useful signal and noise can also be used in stationary gravimetric measurements. For example, in determining the gravitational constant the seismic and microseismic oscillations of the base of this instrument can introduce errors into the measurements. In this case, using the proposed method it is possible to increase the accuracy in determining the gravitational constant.

Thus, in summarizing, the following conclusions can be drawn. On a moving base it is feasible to measure not the individual derivatives of gravity, but the entire set. The local gravitational and inertial fields when measuring the second derivatives of gravitational potential in movement have structural peculiarities making possible a new solution of the problem of discriminating a useful signal against a noise background. Using a priori information on the measured parameter and noise, using the proposed method it is possible to determine the second derivatives of gravitational potential during movement even under the condition of a coincidence of the useful signal and noise spectra.

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## PUBLICATIONS

UDC 550.34

## GRAVITY MEASUREMENT DEVICES, METHODS

Moscow PRETSIZIONNOYE IZMERENIYE SILY TYAZHESTI (Precision Measurement of Gravity) in Russian 1978 signed to press 1 Sep 77 pp 2, 83

/Annotation and table of contents from book by Vladimir Borisovich Dubovskiy, Izdatel'stvo "Nauka", 900 copies, 83 pages/

/Text/ The principles of designing static gravimeters, methods of taking into account their inaccuracy, the prospects of increasing the precision, as well as the possibilities of enlarging the group of problems which can be solved using these instruments are set forth in the monograph. The main units of the system of a stationary automated gravimeter with a multifunctional feedback system, which has been installed on an earthquake-proof platform with an adjustable height, are described.

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PUBLICATIONS

SPACE PHOTOGRAPHY TECHNIQUES AND EQUIPMENT

Moscow KOSMICHESKOYE PHOTOGRAFIROVANIYE (Space Photography) in Russian 1978  
signed to press 19 Apr 78 p 4, 348-351

[Annotation and table of contents from book by B. F. Fedorov and V. D. Perm-  
yakov, Nedra, 3000 copies, 351 pages]

[Text] The present stage of space studies is characterized by the solution  
of a number of urgent problems which are of great importance in various areas  
of human activity. They include the study of natural resources from space.  
In this respect, photography yields the largest amount of information. How-  
ever, to date there has been very little special literature on this subject.

This book contains materials on the fundamentals of automatic photography and  
methods of photography from space. The first part of the book explains the  
structure of the mechanisms and methods for calculating the parts and assem-  
blies of an automatic photographic camera intended for photography from space.  
The second part discusses special features of space photography, gives the  
diagrams and arrangements of various types of equipment, and discusses the  
processing of photographic information. The third part treats the rules of  
the operation of photographic equipment.

The book is intended for engineers and technicians engaged in the development  
and operation of space photographic equipment, as well as for students of  
higher and secondary educational institutions specializing in aerophotogeodesy.

Tables -- 15, figures -- 95, bibliography -- 72 items.

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